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Executive Summary
for
the East Fork Poplar Creek — Sewer Line Beltway
Remedial Investigation Report

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East Fork Poplar Creek – Sewer Line Beltway Remedial Investigation Report

Executive Summary

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contributed to the preparation of this document
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ACRONYMS

ARAR	applicable or relevant and appropriate requirement
AWQC	ambient water quality criteria
BMAP	Biological Monitoring and Abatement Program
BRA	baseline risk assessment
BTF	biotransfer factor
CDI	chronic daily intake
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLP	Contract Laboratory Program
CMS	corrective measures study
COC	contaminant of concern
COPC	contaminant of potential concern
DOE	U.S. Department of Energy
DOE-OR	DOE Field Office - Oak Ridge
DQO	data quality objective
EDXA	energy dispersive X-ray analysis
EFPC	East Fork Poplar Creek
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
ERA	ecological risk assessment
FDA	U.S. Food and Drug Administration
FFA	Federal Facilities Agreement
FS	feasibility study
HEAST	Health Effects Assessment Summary Tables
HI	hazard index
HQ	hazard quotient
IRIS	Integrated Risk Information System
MCL	maximum contaminant level
MLE	most likely exposure
NAA	neutron activation analysis
NCR	nonconformance report
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NPL	National Priorities List
ORAU	Oak Ridge Associated Universities
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PARCC	precision, accuracy, representativeness, completeness, and comparability
PCB	polychlorinated biphenyl
QA	quality assurance
QC	quality control

ACRONYMS (continued)

RCRA	Resource Conservation and Recovery Act
RfC	reference concentration
RfD	reference dose
RFI	RCRA facility investigation
RGO	remediation goal option
RI	remedial investigation
RME	reasonable maximum exposure
SAIC	Science Applications International Corporation
SAP	Sampling and Analysis Plan
SDWA	Safe Drinking Water Act
SEM	scanning electron microscopy
SLB	Sewer Line Beltway
TCLP	toxicity characteristic leaching procedure
TDEC	Tennessee Department of Environment and Conservation
TVA	Tennessee Valley Authority
UCL	upper 95% confidence limit
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

ES.1 INTRODUCTION

On December 21, 1989, the U.S. Environmental Protection Agency (EPA) placed the U.S. Department of Energy's (DOE's) Oak Ridge Reservation (ORR) on the National Priorities List (NPL). On January 1, 1992, a Federal Facilities Agreement (FFA) between the DOE Field Office in Oak Ridge (DOE-OR), EPA Region IV, and the Tennessee Department of Environment and Conservation (TDEC) went into effect. This FFA establishes the procedural framework and schedule by which DOE-OR will develop, coordinate, implement, and monitor environmental restoration activities on the ORR in accordance with applicable federal and state environmental regulations. The DOE-OR Environmental Restoration Program for the ORR addresses the remediation of areas both within and outside the ORR boundaries, including Oak Ridge National Laboratory (ORNL), the former Oak Ridge Gaseous Diffusion Plant (K-25 Site), the Y-12 Plant, Oak Ridge Associated Universities (ORAU), the Clinch River, and East Fork Poplar Creek (EFPC).

This report focuses on the remedial investigation (RI) of the stretch of EFPC flowing from Lake Reality at the Y-12 Plant, through the city of Oak Ridge, to Poplar Creek on the ORR and its associated floodplain. Both EFPC and its floodplain have been contaminated by releases from the Y-12 Plant since the mid-1950s. Because the EFPC site—designated as an ORR operable unit (OU) under the Comprehensive Environmental Response, Compensation, and Liability Act of 1983 (CERCLA)—is included on the NPL, its remediation must follow the specific procedures mandated by CERCLA, as amended by the Superfund Amendments and Reauthorization Act in 1986. Because EFPC involves off-site release of contaminants from the Y-12 Plant, its remediation also must conform with the procedures of Sect. 3004(v) of the Resource Conservation and Recovery Act of 1980 (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984. Because the actions taken to remediate EFPC may affect the environment, the potential environmental impact of those actions must be publicly addressed in accordance with the National Environmental Policy Act (NEPA). The RI of EFPC, conducted from 1990 to 1993, integrated the requirements of these three primary federal regulations, as outlined in the FFA for the ORR, as well as those of other federal and Tennessee state regulations.

The primary steps included in a CERCLA RI are (1) to collect data to characterize, or describe, site conditions; (2) to determine the nature and extent of contamination at the site; and (3) to assess current and future risks to human health and the environment if no remediation occurred. The first two steps are collectively referred to as the *site characterization*, and the third step is termed the *baseline human health and ecological risk assessment*. RCRA calls for similar activities to be performed under a RCRA facility investigation (RFI). After the RI is completed, work begins on the feasibility study (FS) - environmental impact statement (EIS). The purpose of the FS-EIS is to provide decision makers with sufficient information to adequately compare the alternatives for site cleanup, to select a remedy for the site, and to demonstrate compliance with CERCLA remedy selection requirements. During the FS, risk assessment activities initiated under the RI are continued to determine whether the proposed alternatives will significantly reduce the risk to human health and/or the environment. The objectives of the RCRA-required corrective measures study (CMS) are very similar to those of the CERCLA-required FS. NEPA, however, requires that adequate information on the environmental effects of the alternatives be available to aid decision making. In addition, the NEPA "no action" alternative is always considered as a basis to judge the effectiveness and feasibility of all other alternatives. An integrated FS-CMS-EIS considers (1) effects not only on the site itself but also on surrounding communities; (2) socioeconomic impacts; and (3) interactive or cumulative effects resulting from activities at other sites.

This report presents the results of the RI performed for the EFPC OU, which includes the lower 23 km (14.5 miles) of EFPC, its 2.71-km^2 (670-acre) floodplain, and the Oak Ridge Sewer Line Beltway (SLB). EFPC originates on the Y-12 Plant site. From its point of origin at the Y-12 Plant to where it feeds into Lake Reality, the creek is referred to as Upper EFPC. Beginning at the outfall of Lake Reality, Lower EFPC travels through the city of Oak Ridge before re-entering the ORR and joining Poplar Creek. As a result of discharges from the Y-12 Plant, EFPC and its floodplain were contaminated with mercury, other heavy metals, radionuclides, and organic compounds. In addition, the SLB, which was constructed between 1982 and 1983, received soil from the floodplain as fill and topsoil.

A work plan for the EFPC OU, which incorporates both CERCLA and RCRA requirements, was submitted as a two-part Sampling and Analysis Plan (SAP) in December 1991. Part I included a conceptual model and data quality objectives (DQOs), which had not been included in an RFI Plan prepared before the ORR was placed on the NPL. Part II presented the traditional SAP, prepared in accordance with CERCLA guidelines. Field sampling, laboratory analysis, and data evaluation began in the autumn of 1990 and continued through the summer of 1992. A public awareness and participation program, including briefings to the public and to the staff of Region IV EPA and TDEC, was implemented and maintained throughout the RI.

The EFPC RI was conducted in two segments, Phase Ia and Phase Ib. Phase Ia of the RI was designed to determine the nature of contamination and to identify the contaminants of potential concern (COPCs)—primarily mercury and other metals, radionuclides, and organic compounds, including polychlorinated biphenyls (PCBs) and pesticides. Completion of this phase of the RI required installation of 12 groundwater monitoring wells and the quarterly sampling of 22 wells to characterize the groundwater quality and hydrogeology of the floodplain. More than 500 surface water, creek sediment, and surface and subsurface soil samples were taken along the watershed and at a noncontaminated reference site and analyzed for 182 inorganic, organic, and radionuclide analytes as well as geotechnical parameters and soil chemistry related to treatability studies.

Phase Ib, which began in the summer of 1991, was designed to establish the extent and level of contamination. More than 3000 field samples were collected and analyzed, and soil gas surveys were conducted to monitor mercury volatilization. The work conducted under Phases Ia and Ib of the RI was successful in that it enabled determination of the nature and extent of contamination, definition of the potential for migration, and definition of the exposure pathways. The numbers of field and quality control (QC) samples collected during the two phases of the RI are summarized below.

Sample Type	Number of Samples		
	Phase		Total
	Ia	Ib	
Field	569	3445	4014
QC	304	405	709
Total	873	3850	4723

As part of the RI, baseline human health and ecological risk assessments were also completed and are documented in this report. The primary objectives of the baseline risk assessments (BRAs) are to determine whether current and future exposure potential presents an "imminent and substantial" endangerment to human health and the environment, and to evaluate the need for site remediation. The BRAs examine the (1) presence of chemicals and radionuclides in EFPC, (2) potential routes of exposure to human and ecological receptors, and (3) likelihood of adverse health or ecological effects resulting from contact with contaminated environmental media.

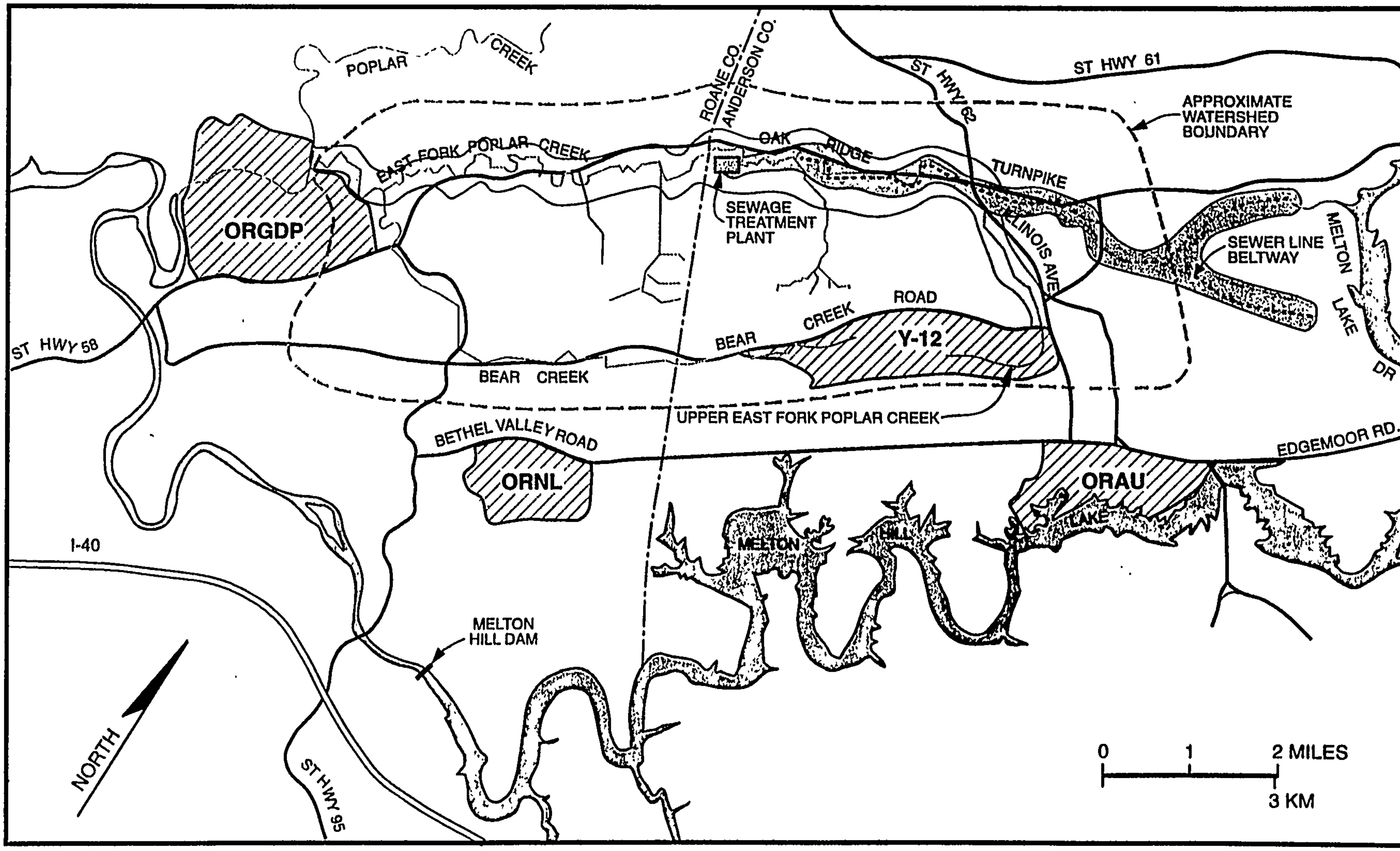
Results of the site characterization and the baseline human health and ecological risk assessment for the EFPC OU are presented in the following sections. The EFPC site characterization, including a discussion of the nature and extent of contamination, is presented first. The assessment of risk is discussed in two sections, the first describing the human health BRA and the second describing the ecological BRA. This executive summary closes with a brief discussion of the remediation goal options for the EFPC OU, which were developed from the primary results of the RI and BRA, and with recommendations to be considered in developing the follow-on FS-EIS.

ES.2 SITE CHARACTERIZATION

ES.2.1 Environmental Setting

EFPC is a perennial stream located in Anderson and Roane Counties in Oak Ridge, Tennessee, ~40 km (25 miles) west of Knoxville (see Fig. ES.1). Its headwaters are contained in 137- to 183-cm (54- to 72-in.) underground collection pipes that extend from the west end to the central area of the Y-12 Plant, where the above-ground portion of the creek begins. From the Y-12 Plant site, EFPC flows northward through a gap in Pine Ridge and enters Gamble Valley and the city of Oak Ridge. From there, the stream flows northwestward along Illinois Avenue through commercial and light industrial areas in Oak Ridge, then trends generally westward, parallel to Oak Ridge Turnpike in East Fork Valley, through primarily residential, agricultural, and undeveloped forest areas, until it joins Poplar Creek. EFPC waters, after entering Poplar Creek, flow into the Clinch River, which is impounded behind Watts Bar Dam.

From the point at which it exits Lake Reality to its confluence with Poplar Creek, EFPC measures ~23 km (14.5 miles). Stream depths range from <1 m to 3 m (3 to 9 ft). The 100-year floodplain bounding the creek varies in width from several meters in its upper reaches to ~500 m (1640 ft) and encompasses ~2.71 km^2 (670 acres). The course and streambed of EFPC have been modified as a result of Oak Ridge development; the creek has been channelized in some sections of town, and riprap has been added to protect the banks. Box culverts and bridge piers are present in EFPC at roadway crossings and numerous drainage ditches, and lateral culverts traverse the floodplain and discharge to the creek. Major tributaries to EFPC include Tuskegee Branch, Mill Branch, Gum Hollow Branch, Pinhook Branch, and Bear Creek. The average flow for EFPC over a 25-year period of record is 1.5 m^3/sec (51.4 ft^3/sec), with artificial flows from the Y-12 Plant and Oak Ridge Sewage Treatment Plant contributing some 40% of that



LEGEND

EFPC floodplain

Sewer Line Beltway

Fig. ES.1. Location map for EFPC and SLB.

flow. These contributions and the general urban and agricultural discharges to the watershed impact the water quantity and quality of the EFPC OU.

The EFPC RI includes the entire SLB, which encompasses over 16 km (>10 miles) of sanitary interceptor sewers and force mains. Construction of the SLB involved use of sediments and soils from EFPC and its floodplain as fill material for portions of the SLB. Contaminated fill was used in pipe trenches in some locations down to 15 cm (6 in.), and floodplain soils were used as topsoil dressing along the line in many areas. The eastern portion of the SLB consists of two branches, one paralleling Emory Valley Road and the other paralleling Warehouse Road. The two branches converge near the Daniel Arthur Rehabilitation Center into a single system that parallels Oak Ridge Turnpike to the Oak Ridge Sewage Treatment Plant (Welch 1987). Because the SLB from Illinois Avenue to the treatment plant falls within the EFPC floodplain, it is not distinguished in this report but rather is incorporated as part of the floodplain discussion. Only that portion of the SLB located west of Illinois Avenue is discussed independently. Several locations along the SLB have already been subjected to remedial actions to allow for new construction; in these cases, contaminated soils/sediments were removed and appropriately packaged for disposal.

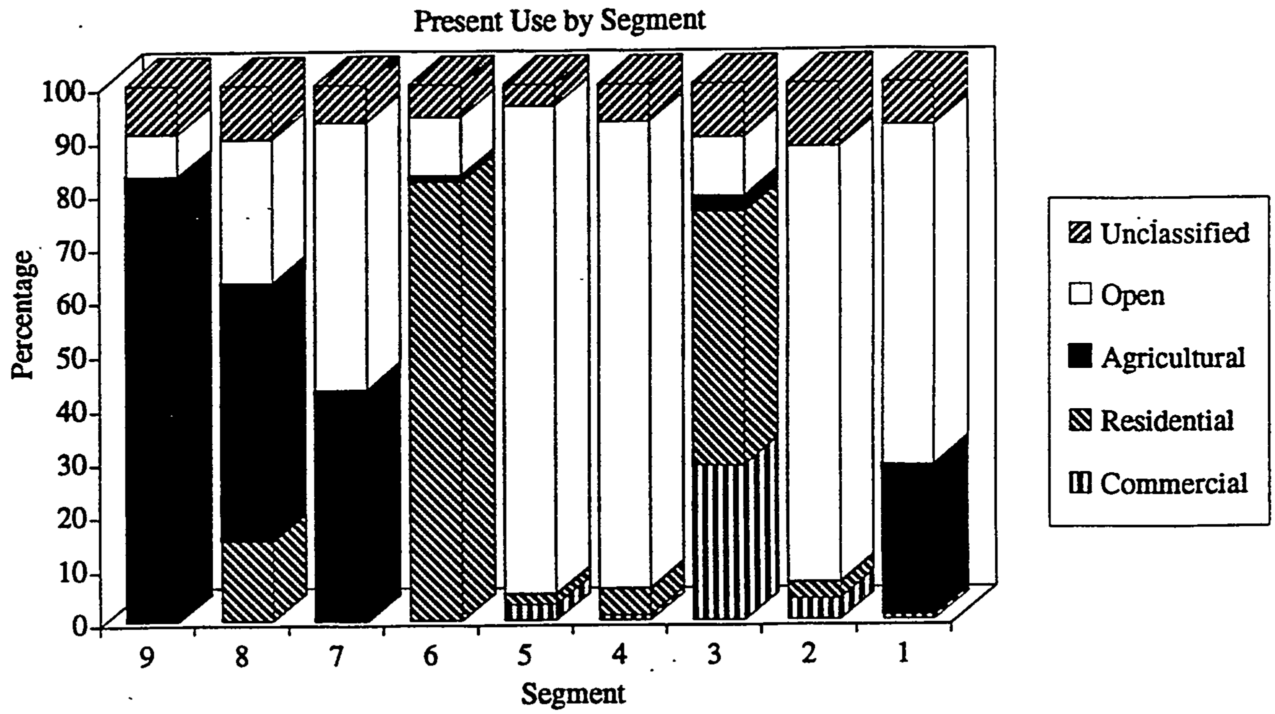
EFPC, for about 25% of its length, traverses DOE property. The remainder of the creek and all of the SLB traverse properties owned by private citizens or the local government. Although the land that falls within the 100-year flood boundaries of EFPC is mostly undeveloped, developed areas occur on adjacent land just outside the floodplain. As a result, land use in the vicinity of the site is diverse, including residential, commercial, agricultural, open (undeveloped) and unclassified (roadways and the creek itself) uses. The residential category includes single- and multi-family housing units and schools. The commercial category includes offices, retail stores, restaurants, meeting places, and other establishments. Agricultural land use within the floodplain itself is limited to grazing of livestock and horses, with no current use for raising crops or family gardens. Open land use areas are those areas involving only incidental use, either through recreation or trespass. (Although the exposure pathways for agricultural and open land use are so similar that they could have been considered together in the baseline human health risk assessment, the BRA took into account the ingestion of crops or livestock raised on the floodplain, which represents a far more conservative case.)

As a basis for investigation, the EFPC and its floodplain were divided into nine segments based on geography, uniformity of land use, and similarity of contaminant levels (see Figs. ES.8 through ES.19 for the location of each segment). Present land use for the nine segments is estimated to be 7% residential, 2% commercial, 52% agricultural, and 31% open land. The remaining 8% of the EFPC site, including the creek itself and all roads and rights-of-way, is unclassified. The total number of individual residences within 150 m (500 ft) of the EFPC and SLB is 1062, with an estimated population of 2622. The Oak Ridge 1988 Comprehensive Plan and current trends toward commercialization and residential development, however, suggest that areas within and adjacent to the floodplain now designated as open space are likely to convert to residential land use in the future. As a result, projected future land use of the EFPC floodplain is estimated to be 29% residential, 12% commercial, 42% agricultural, 8% open, and 9% unclassified. Figures ES.2a and ES.2b show the present and future land use by segment for EFPC and its floodplain.

The EFPC watershed and SLB are located in the Valley and Ridge Physiographic Province of the Appalachian Mountains. This geologic structure produced a topography dominated by narrow elongated ridges and valleys, which trend to the northeast/southwest. The prominent valleys and ridges traversed by EFPC and the SLB are, from north to south: East Fork Valley, East Fork Ridge, Gamble Valley, Emory Valley, Pine Ridge, and Bear Creek Valley. Elevations within the study area range from 400 m (1300 ft) at Pine Ridge to 225 m (740 ft) at the mouth of EFPC. Four different geologic units directly underlie EFPC along its course. These units are, in order of encounter downstream, the Conasauga Group, the Rome Formation, the Chickamauga Group, and the Knox Group. Soil types mapped in the EFPC floodplain belong to the Newark, Newark Variant, Hamblen, Sequatchie, Pope, and Roane Series.

The EFPC site is characterized by cleared areas, shrubs and herbaceous plants, and second-growth trees, which form thick stands up to the creek banks in many locations. Because of different land uses in the past, the woods are in various stages of ecological succession. The floodplain contains areas that have been filled to allow commercial development, and the creek has been channelized in places. Other portions of the floodplain contain agricultural tracts or grass and old field habitats. Terrestrial biota such as deer, raccoons, birds, and insects occur in these habitats. The creek contains several species of fish as well as benthic and other organisms typical of aquatic habitats characterized by limestone rip-rap to smooth and muddy stream bottoms.

Wetlands were inventoried by the U.S. Army Corps of Engineers along the entire length of the EFPC floodplain. Seventeen wetland areas, comprising a total of ~ 5 ha (12 acres), were identified that exhibited all three regulatory criteria (COE 1992) used to define wetlands. Most of those wetlands were < 1 acre in size. Habitats exist within the EFPC floodplain that could support endangered and threatened species, if present.



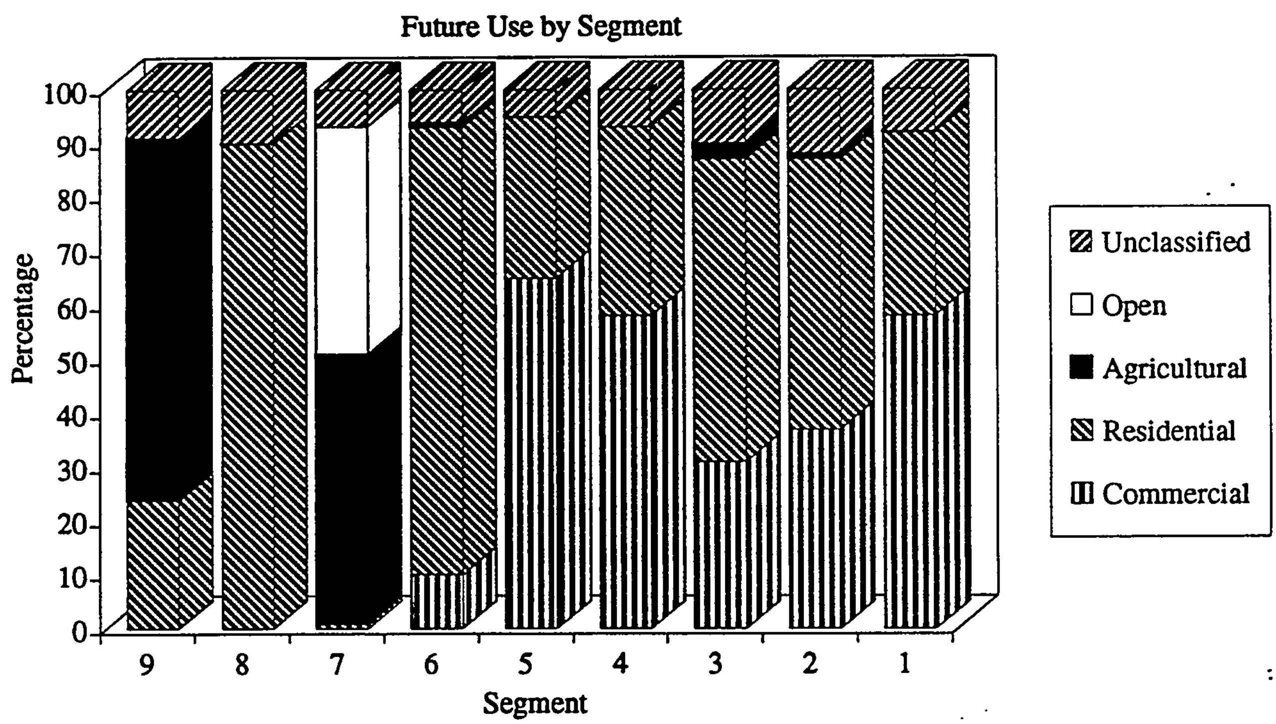
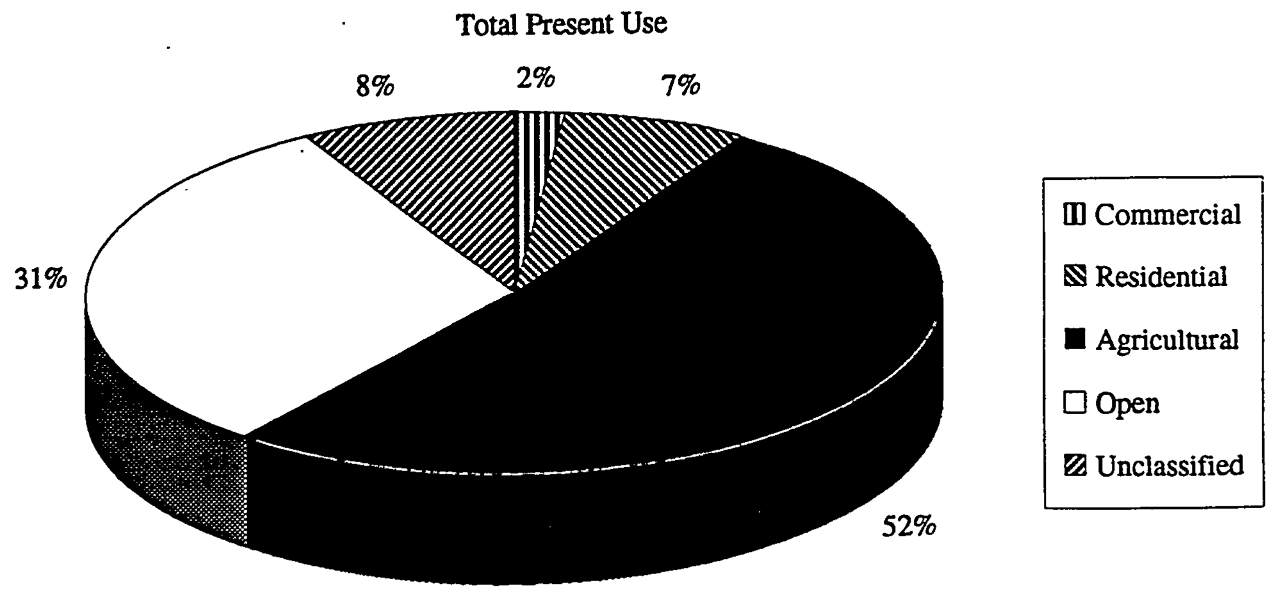


Fig. ES.2a. Present and future land use by segment for EFPC and its floodplain.



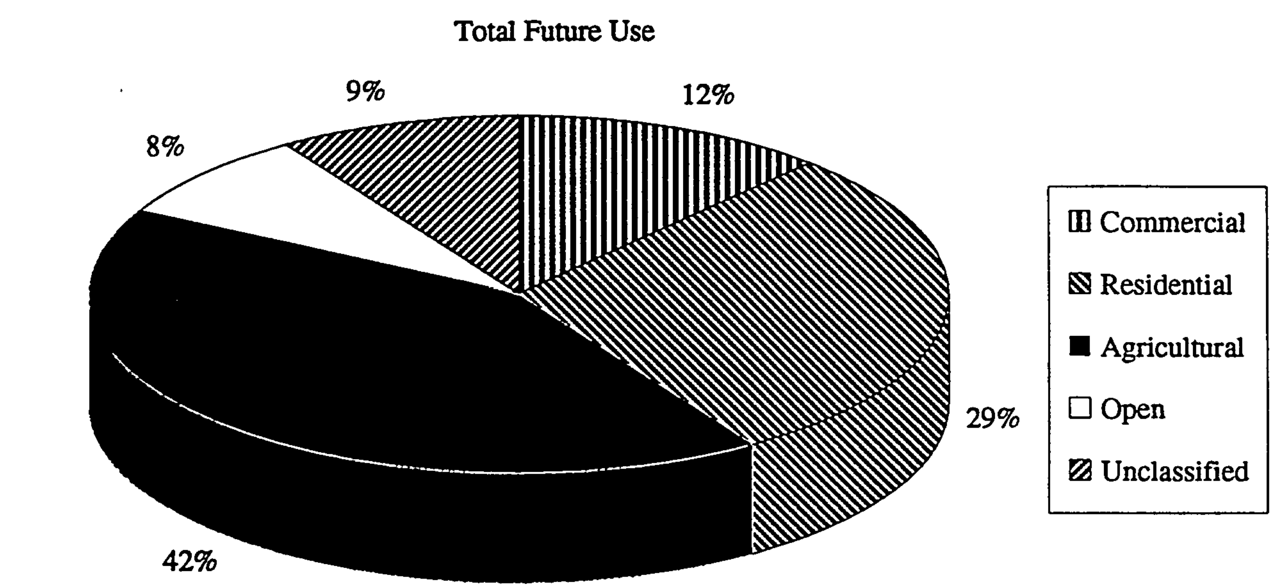


Fig. ES.2b. Total land use percentages, present and future.

The primary climatic attribute affecting possible contaminant transport at the EFPC site is precipitation (and the associated runoff). Precipitation in this area of the Tennessee Valley is seasonally distributed, with peaks occurring in late winter, early spring, and mid- to late summer and lows occurring in the fall. Runoff is greatest in the winter, when evapotranspiration is low and precipitation is high. Precipitation not lost as evapotranspiration or as quick surface and shallow-groundwater runoff percolates through the soil and eventually recharges the groundwater system.

Sediment movement during storm events is the primary natural route of past, present, and future contaminant transport at the EFPC site. The flow of surface water over and through areas of contaminated soils and sediments provides a potential for further transportation and redeposition of material within EFPC. It also provides for direct solubilization of contaminants retained in the contaminated soils and sediments.

EFPC is the primary feature of a hydrologically interconnected network within the EFPC watershed. Within this network, EFPC surface water can recharge the shallow groundwater in a losing reach or, conversely, groundwater can recharge EFPC surface water in a gaining reach. This interrelationship between surface water and groundwater is important because of the potential for continuing movement of contaminants between the two systems.

The shallow aquifer in the EFPC floodplain encompasses both the soil horizon and upper bedrock interval. The soil horizon consists primarily of alluvial silt and clay with lesser amounts of sand and gravel. Thickness of the shallow aquifer ranges from essentially zero to as much as 6 m (20 ft). Water levels in the shallow aquifer fluctuate seasonally in response to variations in recharge and evapotranspiration.

Bedrock is composed primarily of limestone that contains clay and shale partings, but also includes lithologies composed of sandstone, calcareous siltstone, shale, and dolomite. These lithologies typically have tightly bound matrices and insignificant intergranular permeability. However, a moderately well-developed secondary permeability system provides for transmission of water within the bedrock. This secondary system is composed of fractures that commonly intersect one another, providing a significant degree of interconnection in the bedrock aquifer.

Although both lateral flow within the bedrock aquifer and flow from EFPC surface water to groundwater are likely, historic sampling of groundwater monitoring wells within the EFPC floodplain conducted by both the Y-12 Plant and by the U.S. Geological Survey (USGS) suggests that groundwater flow is not a pathway of concern.

ES.2.2 Applicable or Relevant and Appropriate Requirements

To determine the regulatory status of existing conditions for the EFPC site, a comprehensive listing of applicable or relevant and appropriate requirements (ARARs), was developed for the EFPC OU. The ARARs listing is used as a guideline for ensuring that all local, state, and federal laws and regulations affecting EFPC are adhered to. In addition to meeting CERCLA requirements for adherence to the applicable federal or more stringent state environmental laws to ensure protection of human health and environment, the ARARs listing developed for EFPC meets all NEPA requirements.

CERCLA requires that both chemical- and location-specific ARARs must be developed for the RI process. For the EFPC RI-RFI, chemical-specific ARARs were identified for (1) hazardous contaminants in groundwater and surface water, (2) soil and sediments, and (3) radioactive contaminants in all media. The chemical-specific ARARs for groundwater and surface water at the EFPC site arise from the National Secondary Drinking Water Standards and the Tennessee Water Control Act. These two regulations were used to develop chemical-specific maximum contaminant levels, secondary drinking water standards, and water quality criteria for the primary EFPC contaminants. Although no chemical-specific ARARs exist for soils and sediments, TDEC proposed rules, EPA data for PCBs and lead, and Biological Effects Levels from the National Oceanic and Atmospheric Administration (NOAA) for a variety of chemicals were used to provide regulatory guidance as generic action levels. Similarly, guidance from EPA and DOE was used to develop radioactive contamination at the EFPC site. Location-specific ARARs were defined to cover floodplains; wetlands; aquatic resources and natural areas; endangered, threatened, or rare species; and archaeological and historic resources. Details of the specific guidance provided by Federal Executive Orders, the Clean Water Act, Tennessee Water Quality Control Act, Fish and Wildlife Coordination Act, Endangered Species Act, and the Archaeological Resource Recovery Act for these location-sensitive requirements are also provided in this RI report.

ES.2.3 Nature and Extent of Contamination

Several past studies have yielded data concerning the type, extent, and levels of contamination in the EFPC floodplain. Routine monitoring of the Y-12 Plant effluents and EFPC sediments and groundwater has been conducted to varying degrees since 1977, and biological monitoring has been provided at selected locations along the creek since 1984. An investigation undertaken in 1983 as part of the Oak Ridge Task Force Study involved large-scale sediment, soil, water, groundwater, and vegetation sampling in an early effort to understand the potential impact of contamination within the EFPC watershed on human health. Although these and other ancillary studies provide critical information, they lack the degree of rigor and documentation now required by CERCLA. Thus, these study results have only been used for screening-level assessments and for developing conceptual models to define sampling strategies, not as the basis for the human health and ecological risk assessments.

The conceptual model for contaminant transport in the EFPC watershed is based on the premise that soil contamination in the EFPC floodplain is closely linked with hydrologic events. Contaminants from the Y-12 Plant were washed down EFPC during high-flow conditions following rainstorms. At least some of the contaminants were adsorbed onto sediment particles and were transported downstream in a suspended phase (TVA 1985). Other contaminants were transported in a dissolved phase. During flood events, the creek overflows its banks and spreads out across the floodplain, depositing contaminated sediments on vegetation and soils. Hence, the EFPC RI focused on the evaluation of surface water, creek sediments, floodplain soils, and groundwater as potentially affected media.

To determine the nature and extent of contamination at the EFPC site, sampling and laboratory analysis were conducted in two phases. Phase Ia, which began in the autumn of 1990, was designed to determine the nature of contaminants and to identify the COPCs. This phase involved a screening-level assessment for 182 analytes identified from the primary groups of metals, volatile and semivolatile organic compounds, pesticides/herbicides, PCBs, and radionuclides. Phase Ib, which began in the summer of 1991, was designed to establish the extent and level of contaminants observed in Phase Ia. Both Phase Ia and Ib were conducted under Level IV DQOs (established for data used in the BRA), and all analytical analyses were performed under the EPA Contract Laboratory Program (CLP) or approved equivalent.

The primary COPCs for the EFPC site were identified using Phase Ia sampling data and a toxicity concentration scoring system, which ranks potential health effects of contaminants on the basis of measured concentrations and established toxicity measures without making quantitative assumptions about exposures and dose (EPA 1989a). Toxicity measures included both systemic and cancer slope factors. A toxicity score was calculated for each chemical and each chemical was ranked by its percentage of the total score for the group. Those highest-ranked compounds that together represented 99% of the toxicity score for a particular group were considered COPCs. In addition, chemicals were included if their maximum concentrations in groundwater or surface water were greater than the maximum contaminant level established under the Safe Drinking Water Act (SDWA) or federal or state ambient water quality criteria for the protection of freshwater organisms established under the Clean Water Act. Also, several fission products, such as ^{134}Cs and ^{137}Cs, and transuranics were suspected to be in process materials at the Y-12 Plant and were included as COPCs.

As shown in Table ES.1, the COPCs for all EFPC media are extensive. The contaminant listing of 13 heavy metals, 9 polycyclic aromatic hydrocarbons (PAHs), 2 PCBs, and 11 radionuclides, while large in number of compounds, can be more easily interpreted if one considers the relative toxicity percentage of those compounds. For the heavy metals, mercury was by far the most significant contributor, with >85% of the total toxicity (Phase Ia). Similarly, for radionuclides, total uranium (^{234}U, ^{235}U, and ^{238}U) accounted for 98% of the total activity. The organic compound groups of PAHs and PCBs were, in essence, indistinguishable in terms of risk. Hence, the somewhat overwhelming listing of 35 COPCs can be more easily managed by focusing on mercury, uranium, PAHs, and PCBs as representative of the primary contaminant groups.

As noted in Table ES.1, the COPCs for soils and sediments were identical. The metal COPCs for groundwater are similar, except that (1) silver was not detected and barium was included; (2) PAH and PCB concentrations were not significant; and (3) total radium was found at significant levels, but ^{137}Cs was not. COPCs for surface water were developed independently for base and storm flow conditions. Surface water under base flow conditions had contaminant levels which yielded essentially no COPCs. All metals and organics detected are below existing SDWA maximum contaminant levels (MCLs) and meet federal ambient water quality criteria for the protection of freshwater organisms. Radionuclides were detected, as indicated in Table ES.1, but the activity of uranium isotopes and ^{137}Cs was low. Several other radionuclides were included as COPCs because they were not measured in Phase Ia. COPCs for surface water during storm flow included the radionuclides identified for base flow as well as many of the metals identified for sediments.

ES.2.3.1 RI implementation and results

CERCLA requires that DQOs be developed during RI planning to serve as a guide in selecting sampling methods and analytical procedures that will ensure that all data used in developing RI conclusions are technically valid and legally defensible. Identification of the intended data uses is an important part of the DQO development process because they are used to determine the level of data quality required and to define the analytical test parameters. DQOs for the EFPC RI were established during the initial scoping process and were revised prior to Phase Ib of the RI. Meetings were held in 1990 with the primary data users: Region IV EPA, TDEC, DOE, Energy Systems, and the EFPC RI team. Historical data, obtained primarily from

Table ES.1. COPCs by environmental medium

Contaminant	Medium				
	Soil	Sediment	Groundwater	Surface water	
				Base flow	Storm flow
Metals					
Arsenic	x	x	x		x
Barium			x		
Beryllium	x	x	x		
Cadmium	x	x	x		
Chromium	x	x	x		x
Copper	x	x	x		x
Lead	x	x	x		x
Manganese	x	x	x		x
Mercury	x	x	x		x
Nickel	x	x	x		
Silver	x	x			
Vanadium	x	x	x		x
Zinc	x	x	x		x
PAHs					
Benzo(a)anthracene	x	x			x
Benzo(a)pyrene	x	x			x
Benzo(b)fluoranthene	x	x			x
Benzo(k)fluoranthene	x	x			x
Carbazole	x	x			x
Chrysene	x	x			x
Dibenzo(a,h)anthracene	x	x			x
Indeno(1,2,3-cd)pyrene	x	x			x
Pyrene					x

Table ES.1. (continued)

Contaminant	Medium				
	Soil	Sediment	Groundwater	Surface water	
				Base flow	Storm flow
PCBs					
Aroclor-1254	x	x			
Aroclor-1260	x	x			
Radionuclides[a]					
Cesium-134	x	x	x	x	x
Cesium-137	x	x			
Neptunium-237	x	x	x	x	x
Protactinium-233	x	x	x	x	x
Total Radium			x	x	x
Thorium-228	x	x	x	x	x
Thorium-230	x	x	x	x	x
Thorium-232	x	x	x	x	x
Uranium-234	x	x	x	x	x
Uranium-235	x	x	x	x	x
Uranium-238	x	x	x	x	x

[a]Radionuclides are included as COPCs because they were not covered adequately during Phase Ia sampling and analysis.

the Oak Ridge Task Force and the Tennessee Valley Authority (TVA) studies, were reviewed, and a conceptual model was developed. The structure of a phased investigation was conceived, and the overall project objectives were established.

Both qualitative and quantitative DQOs were established for the EFPC RI. Of the PARCC parameters (precision, accuracy, representativeness, completeness, and comparability), analytical precision and accuracy were controlled by adopting EPA CLP criteria and QC frequency and types. Data verification and validation of the resulting analytical data packages ensured that the laboratories produced an acceptable quality level for results. Sampling precision was evaluated by the use of collocated samples (field replicates) and split samples (field duplicates). Representativeness of data from the EFPC RI was accomplished by selecting sampling methods and performing repetitive sampling events to accurately represent the characteristic population. Intervals for soil sampling were chosen to obtain the strata with the highest concentrations of contaminants in order to achieve the most conservative representation and to optimize the number of samples required. DQOs for completeness for the EFPC RI were set at 90% for the laboratory completeness for both Phase Ia and Ib. Percent completeness for field sampling was established at 90% for Phase Ia but only 70% for Phase Ib. To achieve comparability, the EFPC RI used one laboratory to perform its CLP analyses and applied the same sampling methods for each medium.

Data uses were identified during the DQO development process as primary inputs into the site characterization study, the human health and ecological risk assessments, the initial screening of alternatives, the FS, and the EIS. A decision was made to obtain the highest quality data (Level IV) possible for critical studies. The data collection program was compiled into a sampling and analysis plan for each phase of the RI. During the design of the data collection activities for Phase Ib, assistance was obtained from the EPA-Environmental Monitoring Systems Laboratory in Las Vegas. The adequacy of sampling density/data quantity to properly characterize the floodplain was supported by EPA modeling studies using the historic data set. Procedures were adopted or written to guide field activities and data management tasks, and analytical methods were selected for each environmental sampling activity. Phase Ib relied upon neutron activation analysis (NAA), a non-CLP method, for the large-scale soil analysis of the floodplain soil samples to determine the extent and distribution of contamination. DQOs for NAA were established to meet the precision and accuracy of CLP methods but with an exception for analytical sensitivity. The desired lower limit of detection for mercury in floodplain soils was determined to be 11 mg/kg. This limit was established to meet any potential remedial action level or risk-based need.

The EFPC RI was conducted in two phases (Ia and Ib) from 1990 to 1992. Phase Ia of the RI involved collection of base flow surface water and sediment samples from EFPC and its tributaries to define source contributions. Storm flow samples were collected from EFPC during two flood events and from selected tributaries during one flood event. Analyses were performed for filtered and unfiltered samples to distinguish contaminants attributable to suspended particles from those in solution. Groundwater was sampled for four consecutive quarters from 22 monitoring wells. Soil samples for contaminant analyses and undisturbed geotechnical samples for soil chemistry and engineering parameters were taken from three areas of known contamination (NOAA, Bruner's Center, and Sturm sites). Corresponding sampling and analysis were performed at a noncontaminated reference site, Hinds Creek, which was selected because it possesses the same soil and bedrock types but is devoid of any contamination, including urban contaminants. Sampling of the Hinds Creek site was necessary to provide for a true comparison of conditions at the EFPC site with conditions at a noncontaminated reference site, without complications of municipal impacts.

Phase Ib of the EFPC RI was initiated to determine the extent and distribution of COPCs within the floodplain and to support the human health and ecological risk assessments. Extensive sampling of all primary affected media was conducted along the entire length of the EFPC floodplain and the SLB. As shown in Table ES.2, the Phase Ia sampling plan specified soil, sediment, surface water, and groundwater sampling at 5 permanent creek sampling sites, 20 tributaries to EFPC, 3 primary floodplain study sites, and 2 locations on the Hinds Creek reference site. Phase Ib expanded the soil and sediment sampling by conducting soil/sediment sampling in transects across the floodplain at 100-m (330-ft) intervals. Soil samples were taken along each transect at 20-m (66-ft) spacing from the creek bank to the elevation of a 100-year flood. Surface and subsurface core samples were taken to a depth of 123 cm, with >3000 samples collected and analyzed from the 159 transects. Stream sediment samples were collected at odd-numbered transects. Every three sequential sediment samples were composited for analysis to represent 600 m (2000 ft) of the creek. Twenty-seven sediment analyses numbered from 003 to 152 provide results for the full suite of analytes. Soil along the SLB was sampled during Phase Ib, primarily to identify areas of elevated contamination. The results of this extensive sampling and analysis effort along the EFPC and SLB are summarized here. The results of investigations to determine the predominant form of mercury in floodplain soils are presented first, followed by the results of investigations of the principal media.

Mercury Form/Species. A significant effort was directed towards determining the predominant form or species of mercury within the floodplain soils. Because the solubility,

Table ES.2. EFPC RI—media sampling by location

	Tributaries[a]			Creek stations[b]					Study sites[c]			Stream segments[d]										Ref.[e]	
Sample type	BC	CC	TA-TR	LA	LB	LC	LE	LR	NO	BR	WA	1	2	3	4	5	6	7	8	9	SLB	HC2A	HC2B
Soils									×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Sediments	×	×	x	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×
Surface water																							
Base flow	×	×	×[f]	×	×	×	×				×											×	×
Storm flow		×	×[g]	×	×		×																
Groundwater							×		×	×	×												
Geotechnical soils/sediments				×	×	×			×	×	×											×	×

[a]Tributaries: Major tributaries—Bear Creek (BC) and Civic Center (CC)
Minor tributaries—TA to TR (18 total)
[b]Permanent creek sampling stations: Lower East Fork LA, LB, LC, LE, and LR
[c]Floodplain study sites: NOAA (NO), Bruner's Center (BR), and Sturm (WA) sites
[d]Segments (transects): Segment 9 (transects 1-59), 8 (60-64), 7 (65-92), 6 (93-98), 5 (99-105), 4 (106-115), 3 (116-121), 2 (122-143), 1 (144-159)
[e]Hinds Creek reference site: HC2A and HC2B
[f]At tributaries TF, TJ, and TO
[g]At tributaries TF and TO

mobility, toxicity, and biological uptake of mercury change dramatically, depending upon its form, this effort is crucial to the human health and ecological risk assessments. For example, methylmercury is highly toxic and readily absorbed by organisms, whereas mercuric sulfide is relatively nontoxic and has minimal biological uptake. However, direct investigative techniques for determining the form of micron-sized mercury particles are limited. The primary technique for providing direct evidence of a crystalline substance is X-ray diffraction. However, the size of mercury particles in EFPC soils does not lend itself to this technique. Studies are currently underway in the Environmental Sciences Division at ORNL to concentrate the mercury fraction of EFPC soils to a richness which is amenable to X-ray diffraction.

Evidence for the occurrence of mercury in the form of mercuric sulfide in EFPC soils comes from studies using scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDXA). The combination of SEM and EDXA allows the presence of an element(s) to be mapped on the surface of a sample. A universal association of mercury and sulfur in EFPC soils is shown by SEM/EDXA. This is not surprising considering the geochemical affinity for mercury and sulfur to form a stable compound.

The strongest evidence to date showing that mercuric sulfide predominates in the EFPC soils is from wet chemical extraction studies. The proportion of mercury species is determined by compound-specific sequential extractions from soil samples by various chemical solutions. This method indicates that approximately 85% of the mercury in the EFPC soils is in the form of mercuric sulfide (Revis 1989). The EPA laboratories in Las Vegas have developed their own chemical tests for mercury species, and a request is currently being processed for their assistance.

Direct analyses of methylmercury by gas chromatograph and total mercury by atomic absorption were performed on a set of soil samples taken from the EFPC study areas. The proportion of total methylmercury to total mercury averaged about 0.003% (which is in agreement with similar published results), or in the 2 to 80 ng/g (parts per billion) range. As part of the ecological study, the methylmercury attributable to the suspended sediment fraction in surface waters of Lake Reality was analyzed. The proportion of methylmercury in the suspended sediments to total mercury in unfiltered water samples (0.008%) was equivalent to the proportion in soils. Levels of methylmercury observed in these tests indicate that it is not a COPC.

Although the emphasis of these investigations has been to characterize the type of mercury compound present in the soils, the final goal is to quantify the biological availability of the EFPC mercury and the proper absorption factor to be used in the risk assessment. Several solubility studies have been conducted, including application of the toxicity characteristic leaching procedure (TCLP) and performance of bench-scale treatability tests with several common acids. TCLP results were below the detection limit, and treatability extractions achieved <1% dissolution of the mercury from the soils. Solubility studies simulating conditions in the human gastrointestinal tract are now planned by ORNL. If confirmed by the ORNL tests, the realistic absorption of EFPC mercury into an organism is expected to be much less than the 100% now used as a default value.

Soils. Of all the media, the floodplain soils have the largest volume and highest concentration of contaminants. While other COPCs were present in the soil, most attention was directed toward mercury because it accounts for 85% of the total toxicity (from the Phase Ia data). Mercury was found to be a predictor of the occurrence of the other metals and radionuclides and was thus used as a surrogate to determine the distribution and extent of contamination (with the exception of the organic compounds).

As illustrated in Fig. ES.3, mercury (and most other inorganic contaminants) decrease significantly in the lower half of the creek, although elevated concentrations occur at isolated sampling locations throughout the floodplain. In general, however, mercury and the other inorganic contaminants are situated in defined areas of the floodplain and not randomly scattered throughout its length. The creek bank within a few meters of the water has elevated contaminant concentrations along most of its entire length, but the concentrations along the bank decrease as distance from the Y-12 Plant increases. Only four broad areas within the floodplain (NOAA site, Bruner's Center site, Sturm site, and Grand Cove Subdivision) display significantly elevated concentrations of mercury and other metals. Areas that are frequently inundated, such as upstream reaches of the creek behind culverts and roadway underpasses, also show elevated levels. For the uranium isotopes, activity levels were relatively low throughout the length of the creek (see Fig. ES.4), with little discernible pattern of distribution. PCB and PAH concentrations also were found to be low [mean concentrations per segment of <2 mg/kg (ppm) and <5 mg/kg (ppm), respectively]. Their presence is more pervasive and widespread than that of other contaminants, possibly as a result of municipal contributions in addition to the Y-12 Plant source. PCBs and PAHs occur most often in the upper segments of the floodplain near commercial development and urban runoff.

Geotechnical investigations were undertaken to determine engineering parameters, soil chemistry, and hydraulic conductivity for the various soil horizons and to define relationships between particle size distribution and contaminants. The particle size distribution results revealed that mercury is fairly evenly distributed across all size fractions rather than being concentrated

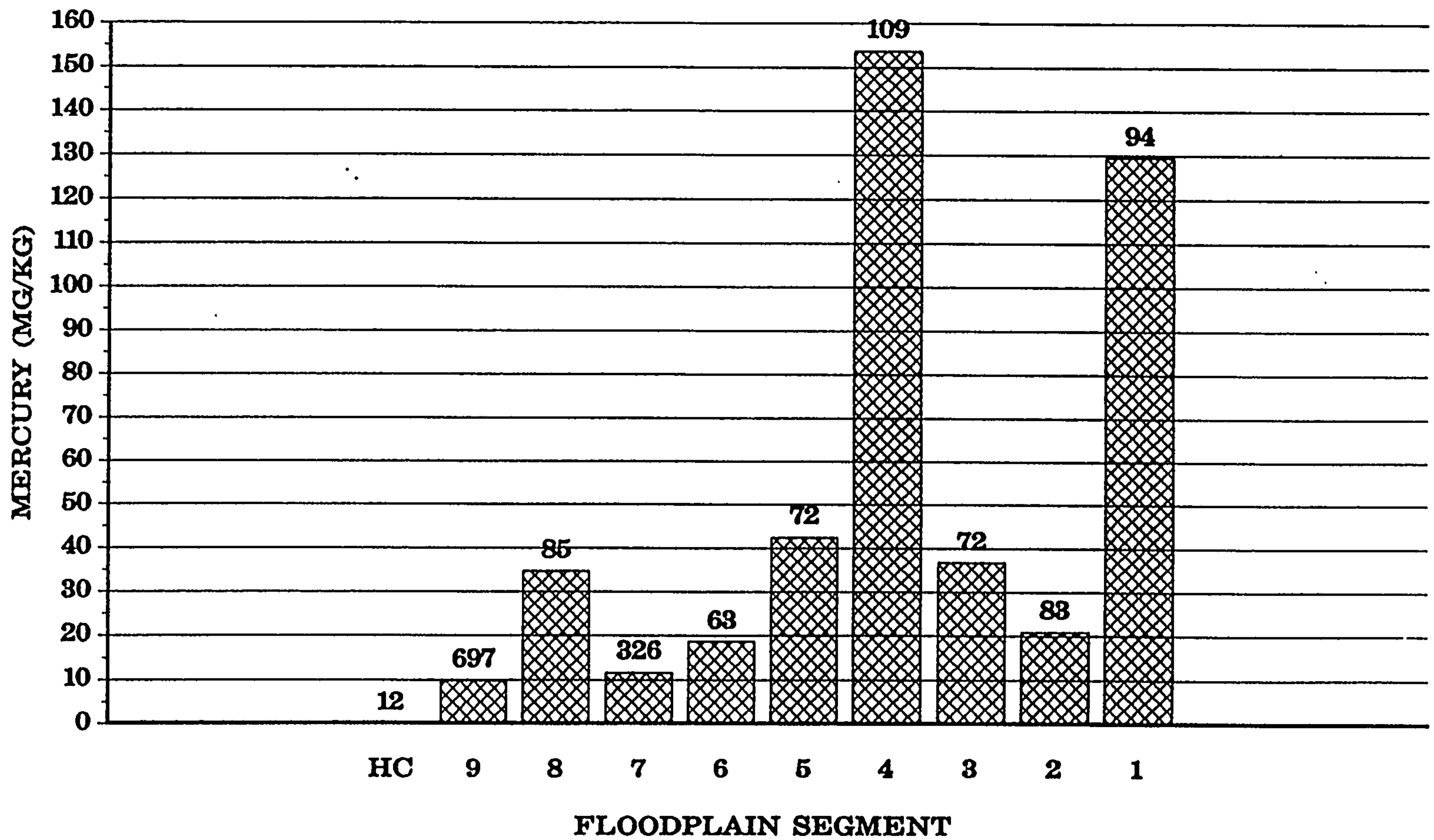


Fig. ES.3. Mean mercury concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

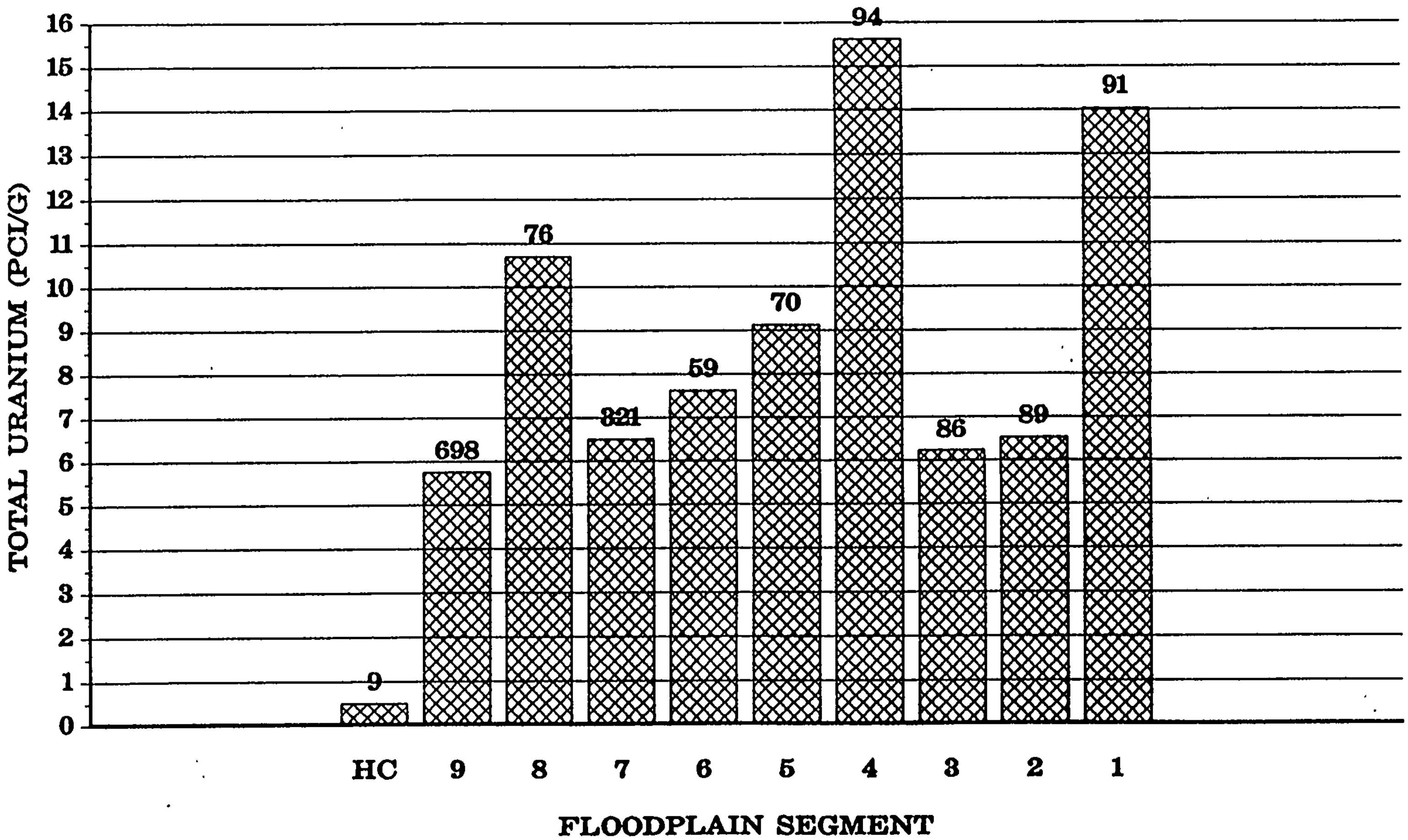


Fig. ES.4. Mean total uranium concentrations (pCi/g) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

in the fine fraction as previous investigations reported (TVA 1985). As shown in Fig. ES.5, mercury levels are highest in Horizon 2 and decrease in Horizon 1, probably reflecting the decreased output of mercury into the EFPC system by the Y-12 Plant in recent years. Similarly, no relationship between uranium concentrations and particle size was apparent. The highest uranium concentrations occur in Horizons 1 and 2, with uranium highest in the fine fraction in Horizon 1 but highest in the coarse fraction in Horizon 2. Uranium levels for the deepest three horizons are relatively constant with particle size classes.

The spatial variability of contaminant concentrations within the floodplain soil was so great that little direct correlation could be made between the overall contaminant concentration of an area and any individual sampling point. Thus, to characterize the level of mercury in floodplain soils, the *extent* or limit of contamination was first bounded by drawing contours of mercury concentrations for 50 and 200 mg/kg (ppm). These contaminant levels were selected to correspond to remedial goals, which are discussed later. To assess the *distribution* of mercury concentrations within the limits of contamination, a geostatistical method called *kriging* was then used to interpolate the concentrations between sampling points. The kriging process calculated mercury concentrations for 20 × 20-m blocks by aggregating the nearest sampling data according to a distance-variance relationship.

By combining the results of the kriging with the hand-drawn mercury contours, volumes of soils containing mercury concentrations > 50 ppm and > 200 ppm were estimated for the EFPC floodplain. Volumes are based on the limits of contamination established for 50- and 200-ppm mercury and for three 41-cm (16-in.) intervals (0-41, 41-82, and 82-123 cm). The total volume of all intervals within the EFPC floodplain containing >50 ppm mercury is estimated at more than 150,000 m^3 (5 million ft^3). A summary of the volume estimates for mercury-contaminated soils, which easily exceeds the range of volumes for other contaminants, is provided in Table ES.3.

Investigations of mercury concentrations in soils along the SLB found elevated concentrations (>50 ppm) to be isolated in three principal areas (Tulane, Fairbanks, and Emory Valley Road areas). The volumes of soil at those sites [286.7 m^3 (10,123 ft^3)] are small compared to the EFPC floodplain volumes. As expected, the measured contaminant types and levels were similar to the distribution found along the creek. Table ES.3 provides estimates of the contaminated soil volumes found at the three primary locations.

Sediments. As would be expected, creek sediments contain the same contaminants as floodplain soils but at lower concentrations. Because of the transient nature of sediments, the

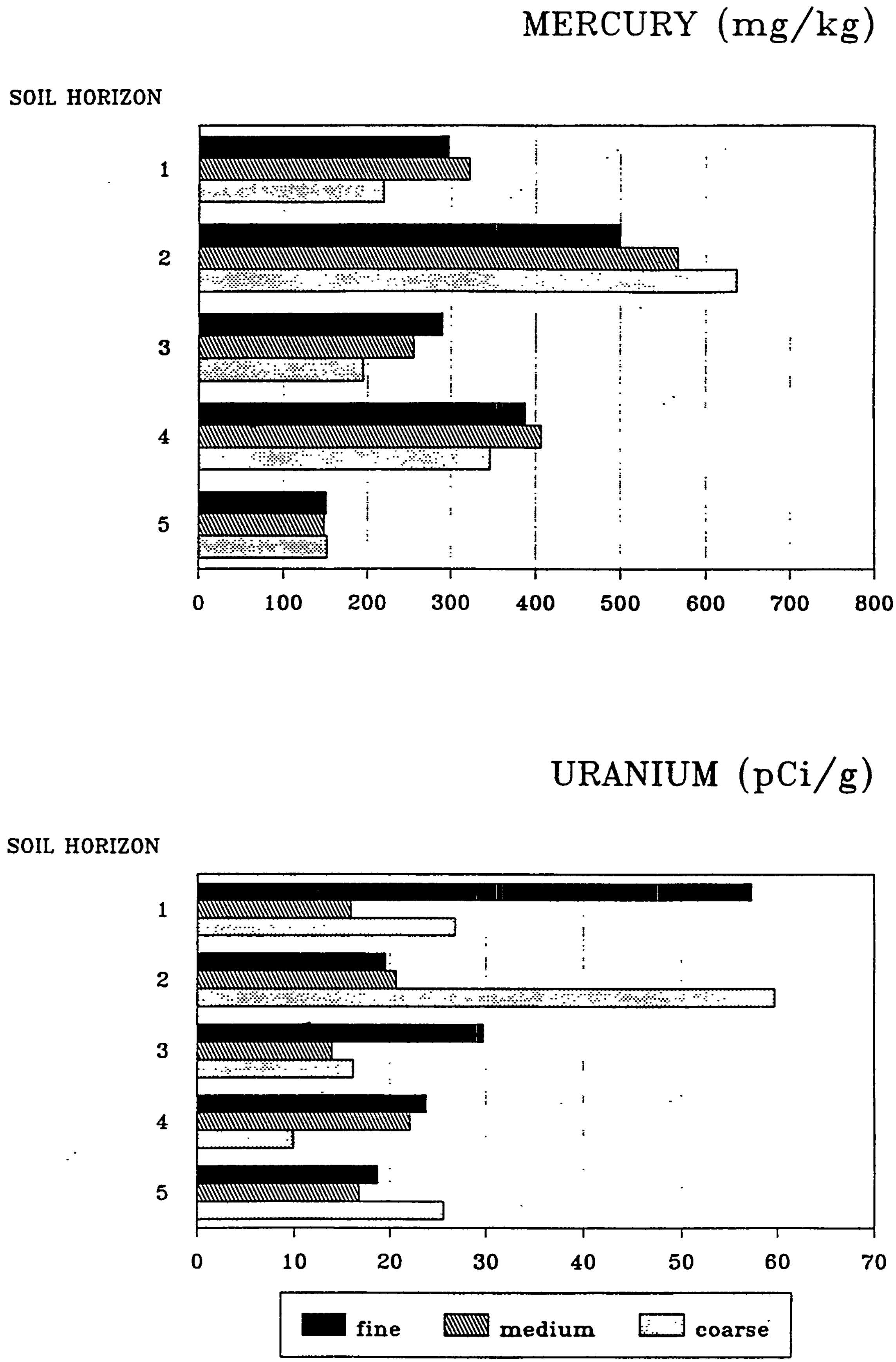


Fig. ES.5. Mean uranium activity and mercury concentrations in EFPC floodplain soils by horizon.

Table ES.3. Volumes of mercury-contaminated soils in EFPC and SLB

EFPC intervals	Soil Volume (1000 m^3/1000 ft^3)	
	≥50 ppm Hg	≥200 ppm Hg
1 (0-41 cm/0-16 in.)	123.8/4371.2	23.6/833.3
2 (41-82 cm/16-32 in.)	26.4/932.1	9.6/338.9
3 (82-123 cm/32-48 in.)	0/0	0/0
Total	150.2/5303.3	33.2/1,172.2

SLB areas	Length (m/ft)			Volume[a] (m^3/ft^3)
	Contaminated	Total	%	
Tulane	15/49	91/298	17%	3.5
Fairbanks	396/299	1615/5298	25%	92.0
Emory Valley	823/2700	2438/7999	34%	191.2
Total	1234/4048	4144/13,596	30%	286.7/10,123

[a]Assumptions: depth 0.152 m (6 in.); width 1.52 m (5 ft)

distribution of metals in EFPC is not as predictable as that in soils. The same general patterns do exist, however. The upper reaches of the creek show somewhat elevated levels of the various metals (especially mercury) compared to other sections of the creek. Figure ES.6 shows the measured mercury concentrations by transect sampling location, with most locations exhibiting <10 mg/kg (10 ppm) in the creek sediments. The few locations showing higher levels of mercury still had contaminant levels below the respective floodplain soils levels (see Fig. ES.3). For total uranium, sediment levels were consistently low (all <12 pCi/g), with a less discernible pattern of contaminant location along the stream length (see Fig. ES.7). The significantly higher concentration of metals (including mercury) and uranium in the EFPC sediments compared to the tributary sediments seems to confirm a Y-12 Plant source for this in-stream contamination. The results of the PCB and PAH sampling indicate contaminant source(s) in the upper third of the creek, immediately downstream of the Y-12 Plant and along the commercial areas of Oak Ridge. The results are indicative of virtually every urban environment and do not necessarily point to the Y-12 Plant as the sole source of these low-level organic contaminants. A sampling results anomaly is observed immediately downstream of the confluence of Bear Creek and EFPC. This area displays slightly elevated concentrations of several contaminants compared to adjacent segments of the creek. This occurrence is thought to result from either the input of Bear Creek or the "pooling" of the sediments from creek back flow. Back flow of EFPC occurs when the Watts Bar Reservoir level is raised and temporary reverse flow takes place in the lower reaches of EFPC.

To determine the location and distribution of sediments within EFPC, sediment accumulations were mapped in the spring of 1992. Field crews walked the creek from Lake Reality to the confluence of EFPC and Poplar Creek. They identified and measured depths at locations of sediment accumulation. Many reaches of EFPC were found to be barren of sediment and to have a bedrock base. The accumulations of sediments that do exist are primarily coarse-grained in nature. Apparently, the normal stream velocity and frequent storm events carry fine-grained sediments downstream to Poplar Creek. Because of the transient nature of sediments within the creek, the data derived from this mapping represent only a gross estimation of sediment location and thickness at a single point in time. Based on this study, an estimated 5.4×10^4 m^3 (1.9×10^6 ft^3) of sediments are present in the creek, only a portion of which would be considered contaminated based on the sampling information presented earlier.

Surface Water. Surface water was sampled during the RI under two scenarios, base and storm flow, to determine present contaminant source contributions to the EFPC watershed. This sampling included locations (1) at the discharge of Lake Reality to measure Y-12 Plant input to

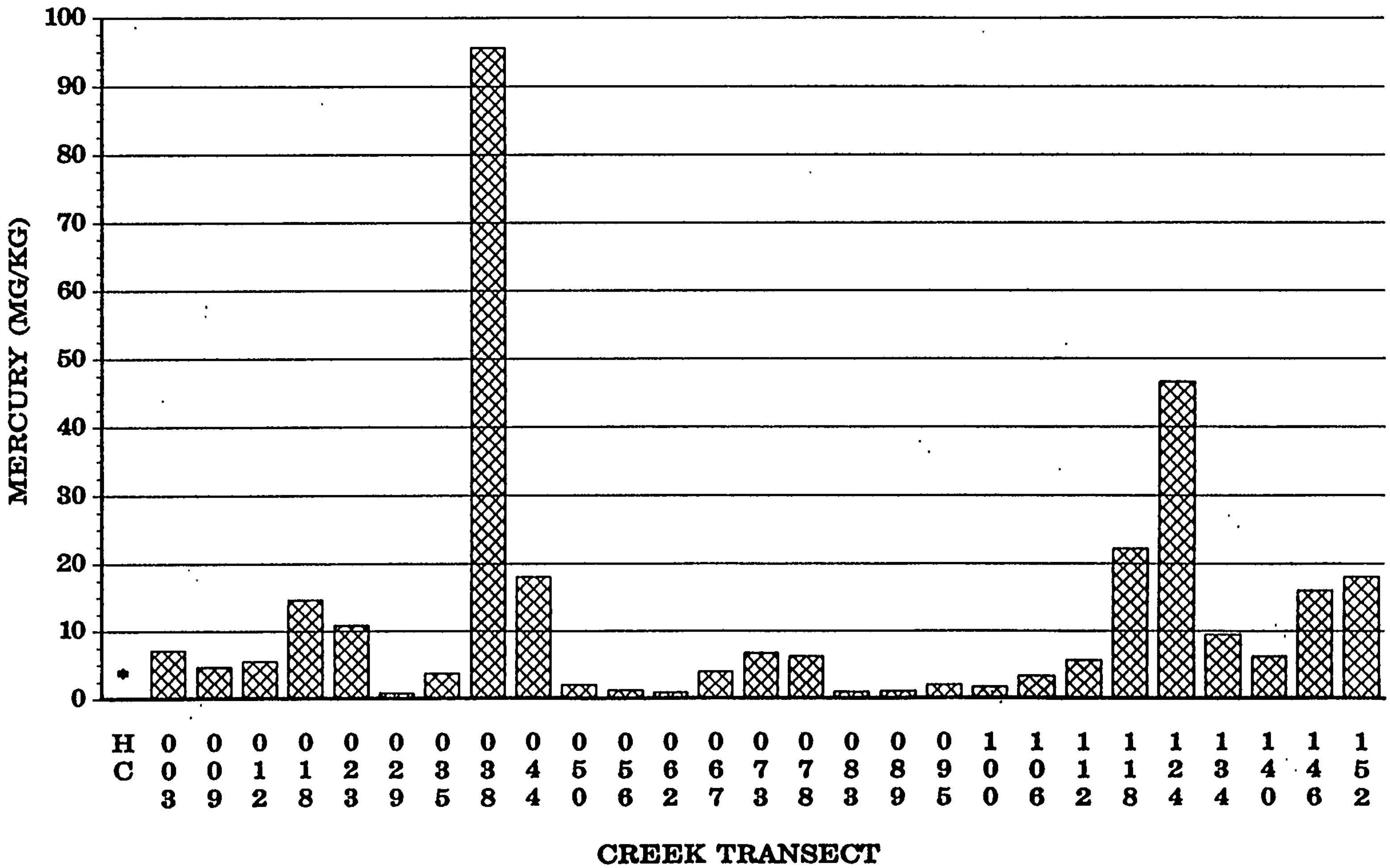


Fig. ES.6. Mercury concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart. The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream. The average of two samples from the reference station is labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

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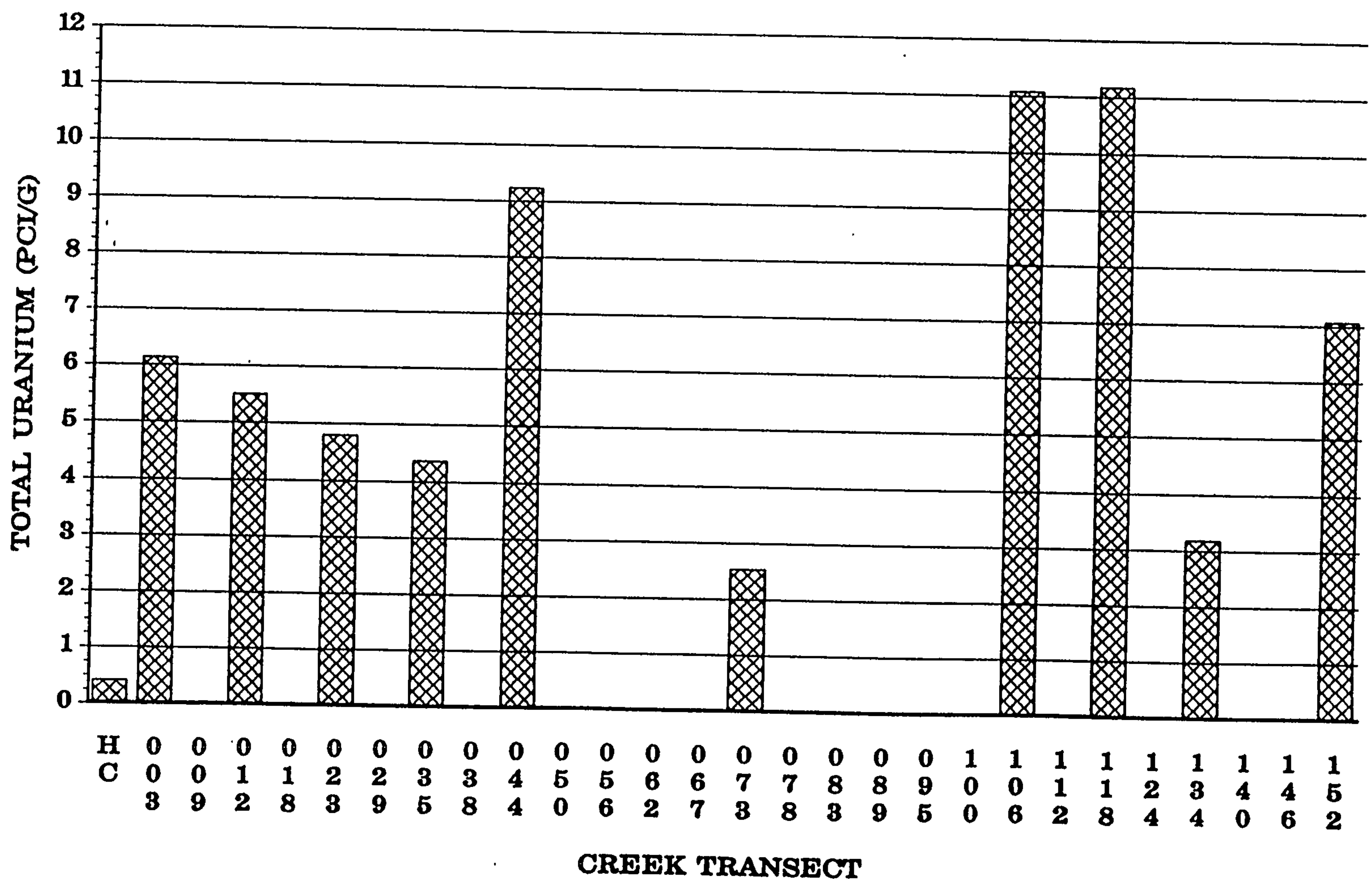


Fig. ES.7. Total uranium concentrations (pCi/g) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart. The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream. The average of two samples from the reference station is labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

the system, (2) at the confluence of EFPC with Poplar Creek to measure output from the system, and (3) at one location adjacent to an area of known high floodplain soil contaminant concentrations. Also, surface water samples were obtained for the six ecological study sites. Except for uranium and one detection of mercury, no COPCs were observed during base flow conditions at any of these creek stations. Three sites also were sampled to characterize potential runoff of pesticides, herbicides, and residual hydrocarbon products from selected residential and commercial areas of Oak Ridge. In addition, two major tributaries—an unnamed tributary (which drains a residential and commercial area near the Civic Center) and Bear Creek (which drains the western half of the Y-12 Plant site)—were sampled. Concentrations at these sites were very similar to the low values obtained for the EFPC sites.

Collection of surface water samples from three EFPC sites during two storm events and from three residential and commercial tributaries during one storm event allowed comparison of base flow and storm flow concentrations of total and dissolved contaminants. Several metals (arsenic, chromium, copper, lead, manganese, mercury, nickel, vanadium, and zinc) were detected at EFPC locations in much higher concentrations during storm flow than during base flow. Detection of no or minimal dissolved concentrations of most metals indicates primarily particle-bound transport. Total activity of uranium isotopes was observed in detectable quantities only in EFPC, but it was present during both base flow and storm flow. Noteworthy by their absence in either storm or base flow, in total or dissolved concentrations, are beryllium, cadmium, and PCBs. No pesticides, herbicides, or high concentrations of heavy metals were detected in adjoining watersheds. Also noteworthy are the presence of chromium, copper, lead, vanadium, and zinc in storm flow samples at the Civic Center tributary and the absence of these contaminants at the other tributaries. These findings indicate impacts on EFPC water quality from urban sources.

Groundwater. Groundwater was investigated as a potential pathway for contaminant migration within the EFPC floodplain. The conceptual model for groundwater indicates that the EFPC valley is an alluvial aquifer receiving surface water from Bear Creek Valley and recharge from the watershed along Black Oak and East Fork ridges. Deep groundwater flow paths are not postulated to cross surface water divides.

Twenty-two wells were sampled for the full suite of analytes for four consecutive quarters. Two types of wells, soil horizon wells and bedrock wells, were installed for the EFPC RI. The soil horizon wells were installed to evaluate the contaminant transfer from soil to the groundwater and to assess the concentration of contaminants within the groundwater in proximity to soil contamination and the creek. Thus, these soil horizon wells, screened from roughly 0.9 to 2.4 m

(3 to 8 ft) at depth, were intended to study contamination in specific areas of concern, not to characterize contaminant migration pathways for human exposure via groundwater. No potable water supply wells now exist within the floodplain, and it is highly unlikely that a future resident would attempt to establish a reliable water supply from a nonproductive (< 1 gpm recharge rate) clay interval at a depth of 0 to 6.1 m (0 to 20 ft). The potential for a groundwater exposure pathway seems even more remote given that (1) a well within the confines of a narrow floodplain would be submerged several times a year due to flooding and (2) a municipal water supply exists throughout the area.

Groundwater field parameters and geochemical analyses were examined to define whether a soil horizon aquifer exists separately from an underlying bedrock aquifer. Hydrogeochemical modeling demonstrated two findings: (1) because no difference could be ascertained between "shallow" and "deep" groundwaters, no aquitard is inferred to exist between the two horizons; and (2) the geochemical environment of the EFPC groundwaters is such that significant mercury concentrations are not likely to persist in a dissolved phase and will precipitate out, most likely as a mercury sulfide.

Filtered and unfiltered groundwater samples were analyzed to compare total and dissolved concentrations of metals because contaminant transport in groundwater is mainly concerned with those contaminants that are found in solution under ambient pH, temperature, and other environmental conditions. As for surface water, most of the detectable concentrations of COPCs found in groundwater were associated with total rather than dissolved analyses. Total concentrations exceeding SDWA levels were found for beryllium, copper, lead, manganese, mercury, nickel, radium, and vanadium, but only manganese, which is a common element in local groundwaters, had dissolved concentrations exceeding the SDWA levels. This association of contaminants with total analyses suggests that the particle-reactive contaminants are attached to fine-grained particles in the total sample and are not necessarily mobile in groundwater. Equilibrium geochemical modeling of the analytical results from the groundwater monitoring wells using MINTEQA2 (EPA 1987) supported the contention that mercury concentrations measured in groundwater samples are related to particulate-bound mercury.

Biomonitoring. A number of historical and ongoing studies, especially the Biological Monitoring and Abatement Program (BMAP), have measured population densities and contaminant body burdens within the aquatic and terrestrial biota of the EFPC watershed. In general, these studies have found elevated levels of mercury and PCBs in fish, with the highest concentrations in the upper reaches of EFPC nearest the Y-12 Plant. Relative abundance estimates of fish collected in the creek indicated that greater densities were present in the upper reaches of the stream, in the area most accessible to the public and also where the highest contaminant concentrations were observed. Other related studies of garden plots and mouse populations have added to the accumulating knowledge of heavy metal (particularly mercury) interactions in the environment. This information base was the starting point for the comprehensive EFPC ecological risk assessment performed for the RI. Further discussion of the scope and results of that assessment is provided in Sect. ES.3.2 of this Executive Summary.

Air Pathway. Atmospheric contaminant concentrations occurring in the general environment around the ORR and the surrounding region are monitored or sampled continuously by an air monitoring network. Measurements of air concentrations (as reported in the annual ORR Environmental Report) of 15 radioactive parameters, fluorides, sulfur dioxides, total suspended particulates, and mercury indicate that the ORR operations are not measurably impacting the regional air quality (including the EFPC floodplain). Ambient air monitoring of mercury also has been conducted by ORNL researchers at EFPC-specific locations selected for known high concentrations of mercury in soil. This monitoring included both high-sensitivity and high-volume measurements. Concentrations were similar to levels at a noncontaminated reference site (within the Y-12 reservation), indicating that mercury concentrations in the air above the floodplain cannot be distinguished from background levels.

Direct Radiation. Historically, most of the large-area radiation survey information on the ORR and in the surrounding area has been provided by the Aerial Measuring System, an aerial radiological surveillance capability maintained by DOE. The most recent Aerial Measuring System survey of the EFPC watershed was conducted during the period of March-April 1992. Measurements were made from a helicopter at an altitude of 46 m (150 ft) and calibrated to terrestrial exposure rates at 1 m above ground level. Gross gamma counts were recorded to determine the ground level exposure rates, and spectral windows were used for photopeak count rates to identify specific man-made radionuclides. Typical background exposure rates (which include the cosmic ray contribution of 3.8 μR/h) vary from 7 to 11 μR/h. Total gamma exposure rates (including background) for the majority of the floodplain range from <8 to 20 μR/h. Only one site within the floodplain (Bruner's Center site) recorded a level in the 13 to 20 μR/h range, and it is subject to a $\pm 30\%$ precision error as determined by the aerial and ground-based control correlation.

ES.2.3.2 Data quality assessment

A primary goal of the quality assurance (QA) program for the EFPC RI was to ensure that the results of analysis of all environmental samples were fit for their intended use. To this end, a QA Program Plan, a QA Project Plan, and field procedures were compiled to guide the investigation. Audits and surveillances were conducted to determine the adequacy of field and laboratory performance against the QA plan and procedures. For the project as a whole, 85 surveillances were performed covering field activities as well as procedural activities such as training and document review. In total, 564 nonconformance reports (NCRs) were written concerning quality deficiencies, and all but a few (which do not affect data use) were resolved.

Analytical data generated under this project have been subjected to a rigorous process of data verification, validation, and review. After data reports were received from the analytical laboratory, verification staff systematically examined the reports following standardized data checklists to ensure the content, presentation, and administrative validity of the data. Discrepancies identified during this process were recorded and documented using the QA Program NCR system.

During the data validation phase, data were subjected to a systematic technical review by examining all analytical QC results and laboratory documentation, following the appropriate functional guidelines for laboratory data validation. The primary objective of this phase was to assess and summarize the quality and reliability of the data for the intended use and to document factors that may affect the usability of the data. As an end result of this phase of the review, data were qualified on the basis of a technical assessment of the evaluation criteria. Qualifiers were generated for each analytical result to indicate the usability of the data for intended uses. For the overall purposes of this investigation, however, data were either accepted or rejected as meeting Level IV quality requirements. With certain exceptions (such as defining the extent of contamination), data from this RI have been used only if they meet the highest qualification criteria established for the human health risk assessment.

To date, procedures for radiological analyses and procedures for radiological data validation have not been firmly established in the same manner as with the inorganic/organic analyses under CLP. EFPC radiochemical analytical data were validated using "Laboratory Data Validation Guidelines for Evaluating Radionuclide Analyses" (SAIC, Rev 4, 1992) and "Laboratory Data Validation Guidelines for Evaluating Neutron Activation Analyses" (SAIC, Rev 2, 1992). These documents were developed with the intent of providing data validation guidelines for radioanalytical data equivalent to those provided by EPA under CLP guidance. These documents provide a systematic process for reviewing the data against the DQOs to provide assurance that the data are adequate for their intended use.

On a project-wide basis, 96% of the data were accepted as usable based on the formal validation process. Of the major analytical groupings, only TCLP and NAA have overall rejection rates exceeding 10%. NAA provided acceptable data for 89% of the analyses, while TCLP provided 82%. Specific analytes that were below the 90% level included:

Group	Compound	% acceptable
Anions	Sulfide	68%
NAA	Antimony Arsenic	87% 69%
Semivolatiles	2,4-Dinitrophenol	89%
TCLP	Phenols Other organics Silver	25% 66-75% 85%

Meeting the 90% level of acceptance for these analyses was not considered critical to the investigation. Sulfide was part of the water analyses and not a COPC. A large number of acceptable antimony and arsenic results (including CLP analyses) are available for soils, even with the low (87% and 69%) acceptance rate for NAA results. The single semivolatile organic compound listed above is only one of several phenols and was not a COPC. The organics from the TCLP samples were not compounds of particular interest. In summary, only a very limited number of analyses did not meet the laboratory objective, and no assessments for the investigation were restricted due to lack of data.

Overall, precision for soils analysis as well as water analysis is considered adequate for the EFPC project. Accuracy on a project-wide basis was deemed acceptable for both CLP analysis and NAA. While some of the data were qualified as usable but estimated, or unusable due to poor matrix spike recoveries, the accepted data are sufficient for use by all phases of the project.

The radiological isotopes of most interest were the uranium series. From the combined use of NAA and alpha spectroscopy, large amounts of uranium data are available for these isotopes. Of all the radiological results, those for thorium had the highest rejection rates, with <50% of the analyses validated as usable data. However, the available results do not indicate that a problem exists, and additional thorium results were not required. Moreover, thorium should be found in the same general areas as uranium; therefore, uranium can act as a surrogate for remedial decisions concerning thorium.

The numbers of samples taken for analysis to characterize the primary media within the EFPC OU are summarized as follows:

Medium	No. samples
groundwater	159
surface water	77
floodplain soils	4181
creek sediments	195
miscellaneous	111
TOTAL	4723

ES.3 RISK ASSESSMENT

Risk assessment is an essential component of the RI/FS process. A BRA is conducted as part of the RI to assess site conditions in the absence of remedial actions. As part of the FS process, risk assessment is used to evaluate the acceptability of proposed remedial actions and as a tool in developing remediation objectives (target cleanup levels). The primary objectives of a BRA are to determine whether there is an "imminent and substantial" endangerment to human health and ecological receptors based on current and future exposure potential and to evaluate the need for site remediation. Separate human health and ecological risk assessments were conducted for the EFPC OU and the SLB; the results are presented in this report and summarized here. Both assessments examined the presence of chemicals in the EFPC OU and SLB attributable to release from the Y-12 Plant, the potential routes of exposure, and the likelihood of adverse effects following contact with contaminated environmental media.

ES.3.1 Human Health Risk Assessment

A phased approach to human health risk assessment was adopted in conducting the BRA for EFPC. This hierarchical approach to risk assessment facilitates derivation of the most scientifically valid estimates of the potential for adverse effects. The primary objective was to focus the evaluation on the receptors and exposure pathways of principal concern and to quantitatively characterize the uncertainty surrounding all assumptions and the resulting risk estimates. Risk assessment has been conducted in three tiers:

- Tier I: screening-level deterministic assessment using Phase Ia monitoring data from locations of (projected) highest concentrations,

- Tier II: deterministic assessment using the full (OU-wide) data set (Phase Ia and Ib), and

- Tier III: probabilistic assessment and quantitative uncertainty analysis using the full data set and focusing on pathways that drive the overall risk assessment.

The human health risk assessment process, as outlined by EPA, is divided into four fundamental component analyses: data collection and evaluation, exposure assessment, toxicity or hazard assessment, and risk characterization. Although an analysis of uncertainty is conducted throughout the risk assessment, uncertainty analysis is presented as a fifth component of the risk assessment process and is included in a separate section.

Data collection and evaluation are the first step in the risk assessment process. All data on chemicals present in environmental media at EFPC were evaluated with the objective of organizing the data into a form appropriate for the BRA. From the full listing of chemicals identified in EFPC, a subset was identified that was of sufficient quality to be used in risk assessment. According to EPA guidance, it is unnecessary to evaluate all chemicals that are found in environmental media. Instead, representative "highest risk" chemicals (COPCs) are selected for study on the basis of (1) environmental concentration and distribution, (2) toxicity or degree of hazard, and (3) mobility and persistence of the chemical in the environment. Exposure point concentrations are then derived for each COPC. Key summary statistics are the arithmetic mean and upper 95% confidence limit of the mean (UCL).

Exposure assessment is the second step in the risk assessment process. The objectives of the exposure assessment are to (1) delineate exposure pathways; (2) identify receptors at risk; and (3) measure or estimate for each receptor the intensity, duration, and frequency of the exposure. EPA has specified that actions at hazardous waste sites should be based on an estimate of the reasonable maximum exposure (RME) expected to occur under both current and future land-use conditions (EPA 1989a). EPA defines the RME as the highest exposure that is reasonably expected to occur at a site. RMEs are estimated for individual pathways and are combined across exposure routes if appropriate.

The third step, **toxicity assessment**, evaluates the inherent toxicity of the COPCs with regard to carcinogenicity and systemic effects. The objectives are to identify and select toxicity measures for use in evaluating the significance of exposure. In the development of these toxicity measures, available dose-response data are reviewed on the adverse effects to human and nonhuman receptors. Toxicity measures used in risk assessment are principally obtained from the EPA Integrated Risk Information System (IRIS), a data base of EPA verified measures.

The final step, **risk characterization**, is the process of integrating the results of the exposure and toxicity assessments; estimates of dose are compared with appropriate toxicity measures to determine the likelihood of adverse effects in exposed populations. Risk is characterized separately for carcinogenic and noncarcinogenic effects because organisms typically respond differently to exposure to carcinogenic agents than they do to exposure to noncarcinogenic agents. For noncarcinogens, toxicologists recognize the existence of a threshold of exposure below which there is only a very small likelihood of adverse health impacts in an exposed individual. It is current EPA policy, however, that any level of exposure to carcinogens is considered to carry a risk of adverse effect.

ES.3.1.1 Data collection and evaluation

Concentrations of COPCs for the EFPC OU were aggregated and statistically evaluated to derive a meaningful estimate of the exposure point concentrations. In human health risk assessment, the exposure point concentration is most commonly an estimate of lifetime average daily intake or dose. The average daily intake or dose was calculated, as required by EPA, from two summary statistics for concentrations of COPCs in environmental media: (1) the arithmetic mean and (2) the UCL. The UCL is the basis for deriving RME estimates.

The EFPC OU is quite large and characterized by a number of different land use types and habitats. To obtain meaningful results from the EFPC BRA, analysis focused on (1) key receptors at potential risk of exposure and (2) the land uses and circumstances under which exposure was most likely to occur. Thus, RME estimates were determined for specific "exposure units" along the length of the EFPC floodplain. Exposure units are geographic areas within which a receptor would realistically be expected to spatially and temporally receive average exposure to contaminants.

To develop exposure point concentrations for each EFPC exposure unit, data obtained from the RI were aggregated using different methodologies for different environmental media. Data for surface water and sediments were aggregated into a single set, representing the entire length of the creek. Data were aggregated in this way based on the assumption that residents of EFPC are free to wander the creek and may be exposed to surface water and sediments at any location along the system. However, in an effort to address isolated areas of contamination, two different sets of exposure point concentrations were used to calculate risk: one includes the UCL on the arithmetic mean as the RME exposure point concentration, and the other uses only the maximum concentration as the exposure point concentration. The analysis was conducted using two different sets of exposure point concentrations at the request of EPA Region IV.

For groundwater, data from the bedrock wells and the soil horizon wells were treated separately, thereby dividing the data into two subgroups. Note that no one is currently using groundwater from either horizon as a source of drinking water, nor is anyone likely to do so in the future.

Three different methods were used to aggregate soil data for EFPC. Although thousands of soil samples were collected, the data set cannot support the derivation of exposure point concentrations for very small exposure units within each land use area (e.g., a quarter of an acre). Therefore, three approaches were adopted to achieve a higher level of spatial resolution for soils.

First, the EFPC floodplain was divided along the length of the creek into nine segments on the basis of geography, uniformity of land use, and similarity of contaminant levels. Each segment was effectively treated as a homogeneous unit with regard to data aggregation and estimation of exposure point concentrations. In this manner, all data within a given segment were combined to calculate a high-end (RME) exposure point concentration, which would conservatively characterize the level of contamination encountered anywhere in the segment.

The second approach was to aggregate the soil data within each segment according to land use. More than one land use often is defined within each segment. Data from each land use area were aggregated so that exposure point concentrations could be calculated separately for each land use area within each segment. The land use area exposure point concentrations were then compared to the segment-wide exposure point concentrations.

The third approach to data aggregation for the EFPC floodplain soils uses geostatistical interpolation methods for spatial evaluation of contaminant concentrations (i.e., kriging). Kriging is a weighted moving average interpolation method that uses the best linear unbiased estimator by weighing the adjacent sample values to calculate an average value for a given region or block.

Two different approaches were used to evaluate levels of chemicals in fish tissue. First, data over the entire length of the creek were aggregated, and a mean and UCL value were derived for the full data set. In the second approach, data were aggregated into three groups representing upper, middle, and lower portions of the creek. This division of the creek into three areas was based on a statistical analysis of difference between sampling locations. The objective of the second method was to ensure that the most conservative exposure point concentrations were developed for use in the BRA.

The SLB was divided into three areas based on observed levels of mercury as an indication of the nature and extent of contamination. These areas are Emory Valley Road, Fairbanks Avenue, and Tulane Avenue. Concentrations of COPCs were aggregated for each of these three areas.

ES.3.1.2 Exposure assessment

The purpose of the exposure assessment is to identify the receptors at potential risk from contact with contaminants, to determine the exposure pathways of importance, and to quantify intake or dose for all contaminants and pathways of concern. The exposure scenarios for the EFPC BRA, based on land use type, include (1) current and future exposure in the agricultural setting, (2) current and future exposure to residential populations, (3) future exposure in the commercial setting, and (4) current and future exposure resulting from occasional use of open land. The receptor groups at greatest risk of exposure were assumed to be children and adults who reside in the community along EFPC. For each exposure scenario and receptor group, the intensity, duration, and frequency of exposure were characterized.

The exposure evaluations were based on RME exposure assumptions. EPA Region IV requested that RME values be used as the principal basis for risk assessment of EFPC. MLE (most likely exposure) estimates were also calculated as a point of comparison but were not included in the risk characterization section of the report (see Appendix M). The RME estimate is not a "worst case" measure, but a high-end, conservative estimate of exposure in the population at potential risk. In addition to RME point estimates, Monte Carlo simulations were used to generate probabilistic estimates of exposure and risk that were used in uncertainty analysis and to supplement the single-point RME estimates.

Current and future exposure pathways for residential receptors are as follows:

- dermal exposure to surface water while swimming,
- dermal exposure to surface water while wading,
- incidental ingestion of surface water while swimming,
- dermal exposure to sediments while wading,
- dermal exposure to soil,
- incidental ingestion of soil,
- ingestion of groundwater and inhalation of groundwater vapors (future exposure only),

- ingestion of homegrown produce, and
- ingestion of recreationally caught fish.

Current and future exposure pathways for the agricultural setting include those identified for residential exposure plus the following:

- ingestion of home-raised beef,
- ingestion of home-produced milk (future exposure only), and
- inhalation of particulates while mowing.

Risks to both children and adults were assessed for both the current and future exposure scenarios. Two age groups of children were assessed: 3 to 12 years for RME and 6 to 9 years for MLE.

The open land use scenario is designed to account for occasional exposure to EFPC soils, surface water, and sediment by individuals who are not residents of the EFPC community. Exposure was assessed for both children and adults, with the assessment of children focusing on ages 9 to 18 for the RME and on ages 12 to 15 for the MLE. For children, exposure pathways included only the first six pathways identified above for residential receptors and were of shorter durations and lesser frequencies than for adults.

All commercial zones within the vicinity of the EFPC OU occur on paved areas located at a distance from the creek and outside the floodplain. Therefore, the BRA assumed no exposure of commercial receptors to contaminants under the current land use scenario. Future use of commercial land assumes exposure only via the groundwater pathway. For the business community, the only pathway evaluated was ingestion of groundwater by adult receptors. This is a very conservative assumption because the availability of municipal water makes it unlikely that groundwater will be a source of drinking water, either now or in the future.

Ideally, exposure factors should be derived from estimates of site-specific activities and behavior patterns of receptor groups at potential risk of exposure. Because of the size of EFPC, such information could be meaningfully developed only through a large-scale survey of Oak Ridge residents and was not developed for the EFPC BRA. In the absence of such data, EPA guidance was used whenever possible in selecting or deriving values for exposure variables. The principal sources of information used are *Superfund Exposure Assessment Manual* (EPA 1988), *Exposure Factors Handbook* (EPA 1989b), *Risk Assessment Guidance for Superfund: Human Health Evaluation Manual* (EPA 1989a), *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors* (EPA 1991), and *Dermal Exposure Assessment:*

Principles and Applications (EPA 1992a). Exposure factors for adults were assumed to remain relatively constant over the duration of exposure. However, because exposure factors vary as children grow to adulthood, weighted-average values were used to characterize RME estimates for children over a specified period of time.

To estimate uncertainty in the exposure assessment, a probabilistic method using Monte Carlo simulation was applied. Exposure variables were characterized by probability density functions that reflect the inherent variability in the exposure factors. In looking at the probability density functions for the exposure variables, one sees that the RME point estimates are generally quite conservative and fall within the upper tail (>90%) of the probability distribution. This pattern is expected, given the responsibility of the regulatory agencies (in light of the inherent variability and uncertainty in risk assessment) to ensure protection of human health.

ES.3.1.3 Toxicity assessment

The purpose of the toxicity assessment is to evaluate the inherent toxicity of the COPCs and to identify and select toxicity measures for use in estimating risk to receptors. The BRA for EFPC required the selection of toxicity measures for both chemical compounds and radionuclides. The toxicity measures used for chemical compounds were:

- reference doses (RfDs) for oral exposure -- acceptable intake values for subchronic and chronic exposure (noncarcinogenic effects),
- reference concentrations (RfCs) for inhalation exposure -- acceptable intake values for subchronic and chronic exposure (noncarcinogenic effects),
- cancer slope factors (i.e., cancer potency) for oral exposure, and
- cancer slope factors for the inhalation route.

EPA derives RfDs for noncarcinogens from estimates of the no-observable-adverse-effect level or lowest-observable-adverse-effect level in humans or test animals. The inhalation RfC is also derived from the no-observable-adverse-effect level, but requires conversion of the levels observed in animals to human equivalent concentrations before data sets and effects levels can be evaluated and compared.

The assessment of the potential for noncarcinogenic effects (i.e., the use of RfDs and RfCs to assess risk) is based on the assumption of a threshold below which health effects are not expected to occur. Carcinogenesis, however, is thought to be a phenomenon for which the presumption of threshold effects is inappropriate (EPA 1989a). Therefore, rather than estimate an effects threshold for these chemicals, EPA first assigns a weight-of-evidence classification and then calculates its cancer potency, or slope factor. Weight-of-evidence classifications include (1) A, human carcinogen; (2) B1, probable human carcinogen based on availability of limited human data; (3) B2, probable human carcinogen based on availability of sufficient data in animals but inadequate or no data for humans; (4) C, possible human carcinogen; (5) D, not classifiable as to human carcinogenicity; and (6) E, evidence of noncarcinogenicity for humans. EPA develops a cancer slope factor, which is a plausible upper-bound estimate of the slope of the dose-response curve in the low-dose range, for all chemical compounds that have been classified as definite, probable, or possible human carcinogens.

EPA has not developed RfDs or slope factors for dermal exposure. In the absence of these factors, the toxicity measures for oral exposure were used in the EFPC BRA to calculate dermal exposure, as recommended by EPA (EPA 1992a). Information for identifying and selecting toxicity measures was obtained from the two sources recommended by EPA, IRIS and Health Effects Assessment Summary Tables (HEAST), with priority given to IRIS. Toxicity measures used for all COPCs and the toxicological information used to select those measures are provided in the BRA.

No EPA-verified oral and inhalation RfDs are currently available for mercury in the IRIS data base. EPA is evaluating the potential noncarcinogenic effects of mercury and has, in the interim, published a tentative oral RfD of 0.0003 mg/kg (ppm) per day for inorganic mercury based on the effects of mercuric chloride in rats. Because mercury is the primary contaminant of concern (COC) at EFPC, information on the bioavailability and physicochemical properties of mercury is critical to accurately characterizing risk to public health.

During the RI, chemical analysis of the soil samples collected from the EFPC floodplain indicated that mercury was predominantly present in an insoluble form, probably as mercuric sulfide (Revis et al. 1989). The toxicity and bioavailability of mercury closely parallel its solubility in the aqueous media. The existing RfD for mercury is based on exposure of laboratory animals to mercuric chloride, which is a highly soluble form of mercury. Mercuric sulfide is a less bioavailable, less toxic form of mercury. However, the EFPC BRA conservatively assumed that all mercury in the EFPC OU was present in the most bioavailable, most highly toxic form. This assumption resulted in very conservative (highly protective) estimates of risk to human health.

ES.3.1.4 Risk characterization

Risk characterization integrates the results of the exposure and toxicity assessments by combining estimates of dose with appropriate toxicity measures to determine the likelihood of adverse effects in exposed populations. Risks are calculated for each chemical or radionuclide, each pathway, each receptor group (adults and children), each current land use scenario, and each future land use scenario. These individual risks are then summed over chemicals or radionuclides and pathways to obtain a total risk for each receptor group and for current and future land use scenarios. These total risks are calculated differently for each of three contaminant types: (1) chemical carcinogens; (2) chemical noncarcinogens; and (3) radionuclide carcinogens. For each of these contaminant types, there is a different equation for estimating risk, but all integrate the exposure and toxicity assessments. COPCs for which calculated risks exceed EPA targets are classified as COCs.

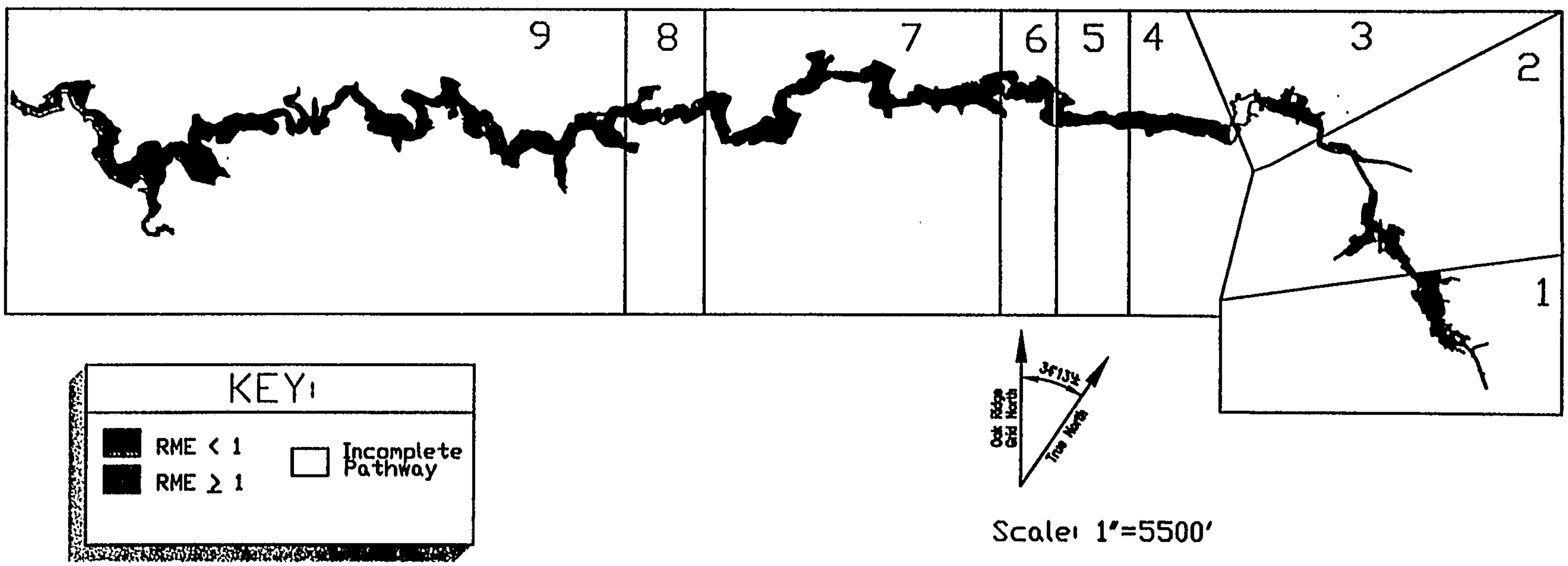
Table ES.4 identifies the exposure and toxicity measures, the equations for calculating risk, the methods for combining results in deriving an estimate of total risk, and EPA target risk levels. For the EFPC BRA, risks were presented for individual pathways and exposure routes and were also summed across multiple pathways and exposure routes. Note that the combined risk estimates are very conservative because they are simple summations of the results across all pathways to a single receptor. It is unlikely that a human receptor would aggregate exposure in this manner.

A tiered approach to risk characterization was implemented for the EFPC BRA, beginning early in the RI process. The first tier was a screening-level deterministic risk assessment using data from Phase Ia from the known areas of high mercury contamination. This assessment was performed to estimate the magnitude of potential risks and to help identify important pathways and COCs. The second tier was a deterministic risk assessment using all validated data. The final tier was a probabilistic risk assessment and quantitative uncertainty analysis using Monte Carlo simulations. Because the first tier was only useful during the early stages of the RI and is essentially a subset of the Tier II analysis, it is not discussed here.

Tier II. None of the Tier II risk estimates indicate an imminent or substantial endangerment to human health requiring immediate, short-term measures. The most substantial risk levels are associated with exposures that are hypothetical and highly uncertain (e.g., the food chain pathways). The Tier II results indicate that cancer risks from radionuclides on the EFPC site consistently fall either below or within the EPA target cancer risk range of 10^{-6} to 10^{-4}. In the case of nonradionuclide chemicals, however, both noncancer and cancer risk estimates exceed EPA targets. Results of the Tier II assessment are illustrated in Figs. ES.8 through ES.19. These maps show summed RME risks that account for multiple contaminants and pathways for each receptor group (adult and child), for both current and future land use scenarios, within the nine EFPC segments.

Table ES.4. Risk measures and equations for risk

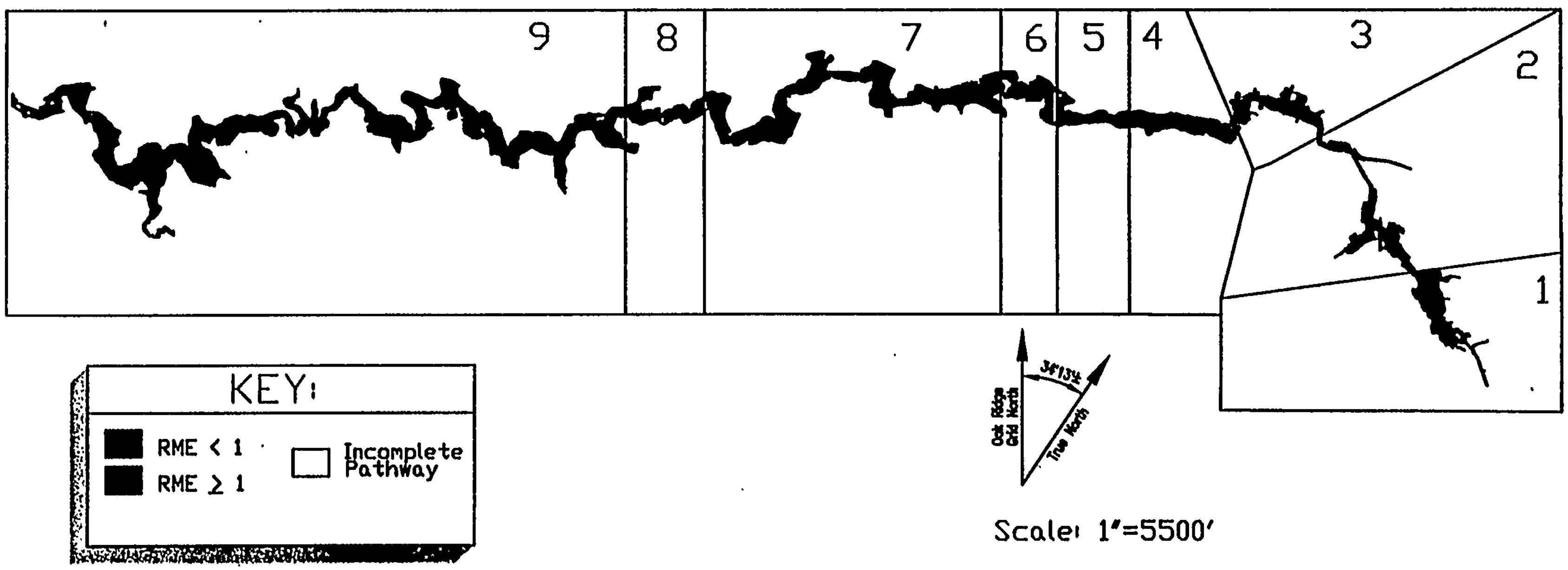
Contaminant type	Risk measure	Exposure measure	Toxicity measure	Individual contaminant risk equation	Total risk	EPA guidance on acceptable risk
Chemical carcinogens	Upper bound estimate of excess lifetime cancer risk to an individual	CDI - chronic daily dose averaged over a 70-year period (CDI = chronic daily intake)	CSF = 95% upper bound estimate of slope of dose-response relationship (CSF = cancer slope factor)	$Risk_i$ = CDI × CSF i = chemical	$\sum_{i=1}^{n} \sum_{j=1}^{p} Risk_{ij}$ where i = chemical j = pathway	Risk ≤ 10^{-6} or 10^{-6} ≤ Risk ≤ 10^{-4}
Chemical noncarcinogens	HQ = hazard quotient: potential for adverse noncarcinogenic effects	CDI = chronic daily dose averaged over the exposure period	RfD = acceptable daily intake for subchronic and chronic oral exposure or RfC = acceptable daily intake for subchronic and chronic inhalation exposure	HQ = CDI/RfD HQ = CDI/RfC	$HI = \sum_{i=1}^{n} HQ_i$ i = chemical (HI = hazard index)	HI < 1
Radionuclides (all carcinogens)	Excess lifetime cancer risk to an individual	IR = daily intake rate and EF = exposure days per year	SF = age- and sex-specific coefficients for individual organs receiving radiation doses combined with organ-specific dose conversion factor (SF = slope factor)	$Risk_i$ = C × IR × EF × SF where C= concentration i = radionuclide	$\sum_{i=1}^{n} \sum_{j=1}^{p} Risk_{ij}$ where i = radionuclide j = pathway	Risk ≤ 10^{-6} or 10^{-6} ≤ Risk ≤ 10^{-4}



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

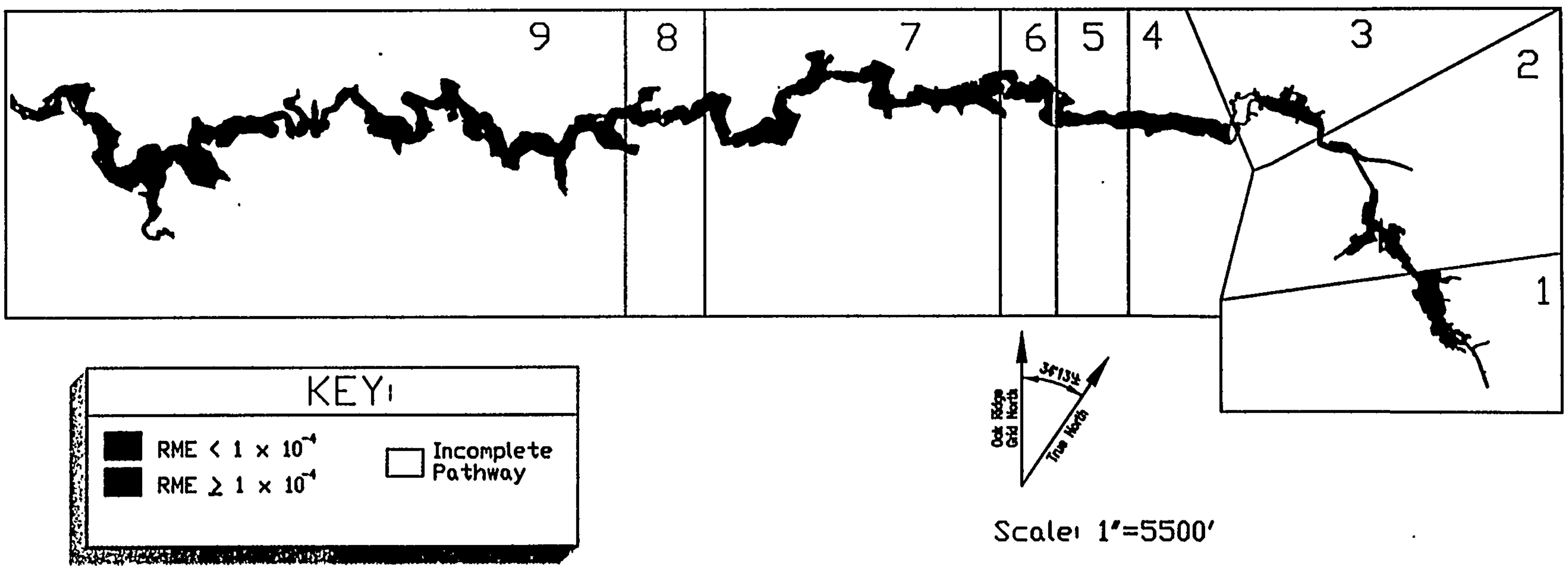
Fig. ES.8. Hazard index for noncarcinogens for adults under current land use scenario.



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

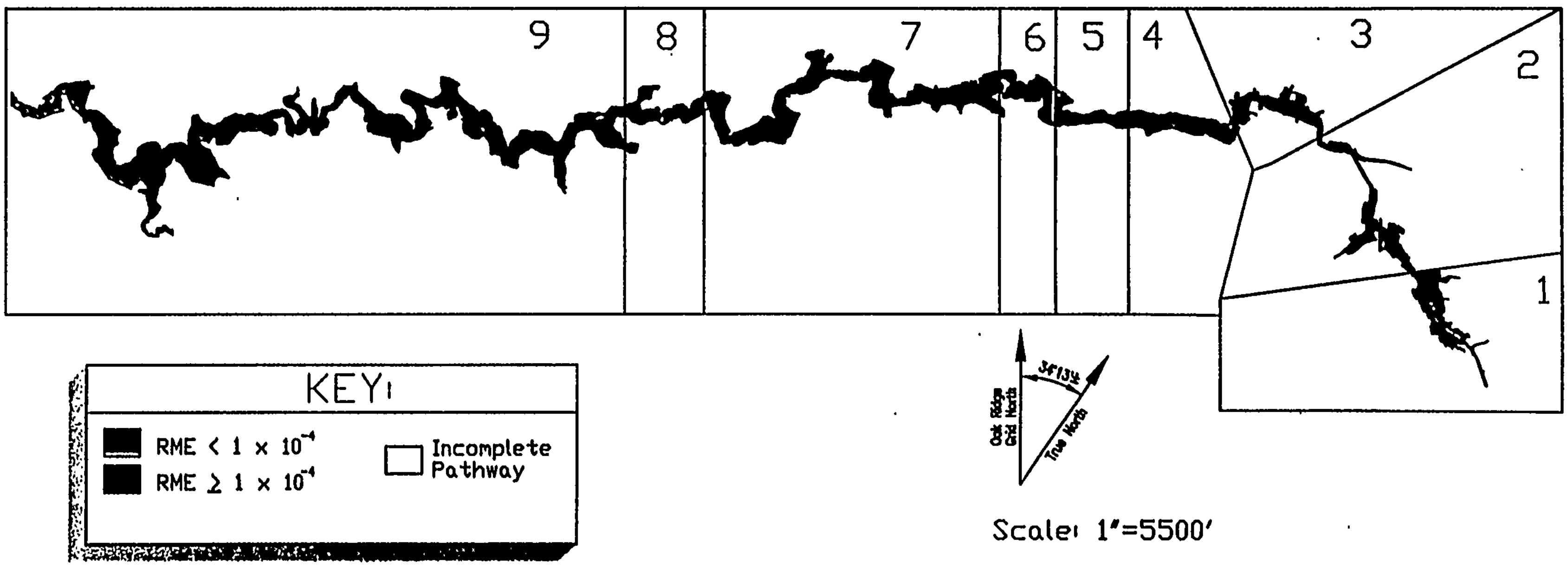
Fig. ES.9. Hazard index for noncarcinogens for adults under future land use scenario.



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

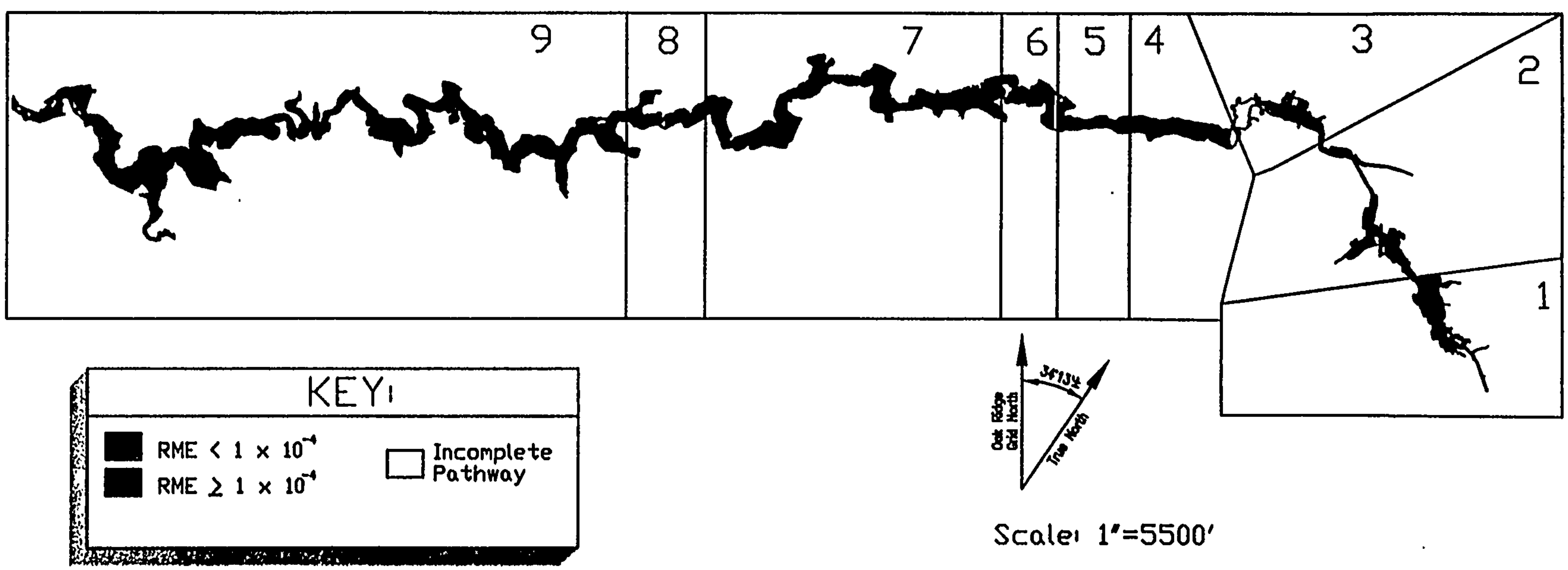
Fig. ES.10. Excess cancer risk for carcinogens for adults under current land use scenario.



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

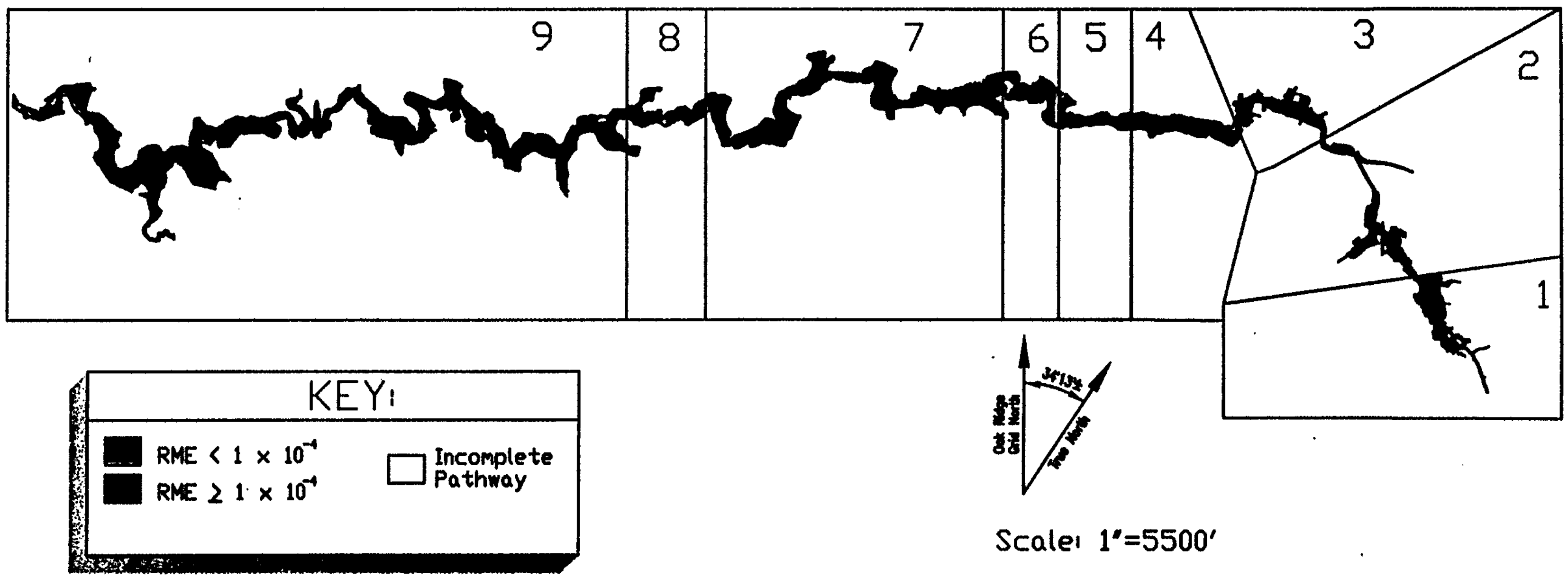
Fig. ES.11. Excess cancer risk for carcinogens for adults under future land use scenario.



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

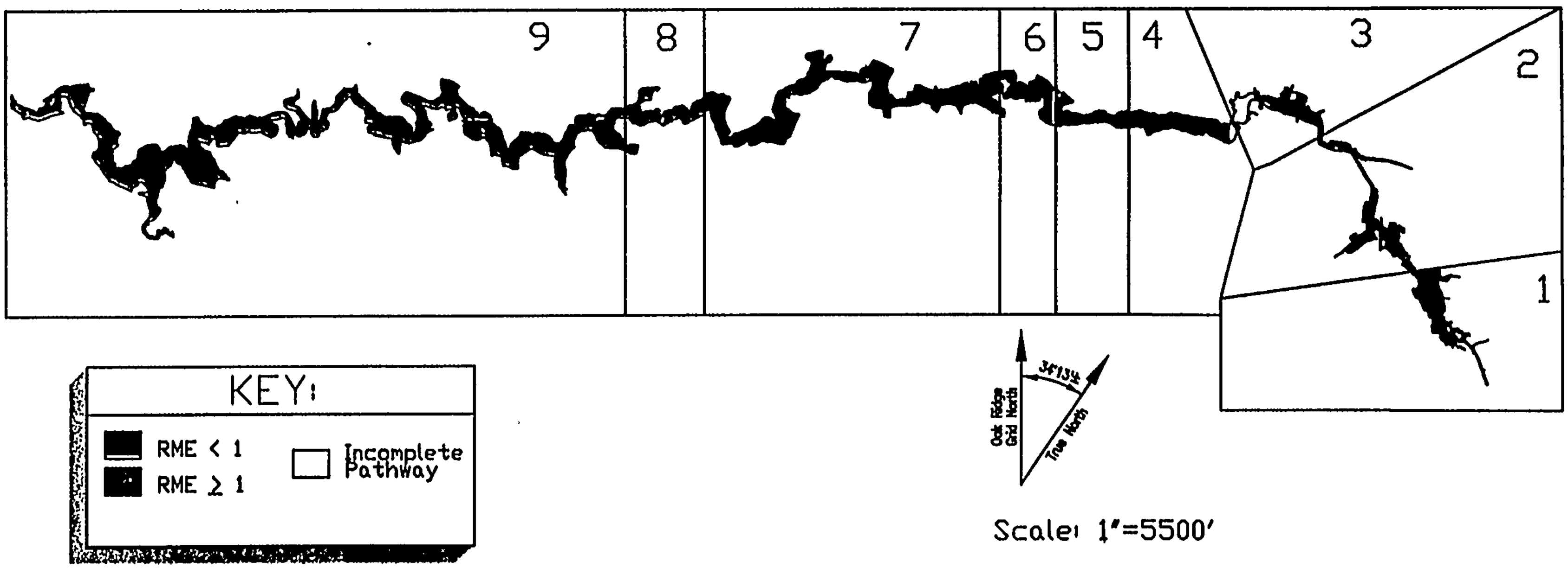
Fig. ES.12. Excess cancer risk for radionuclides for adults under current land use scenario.



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

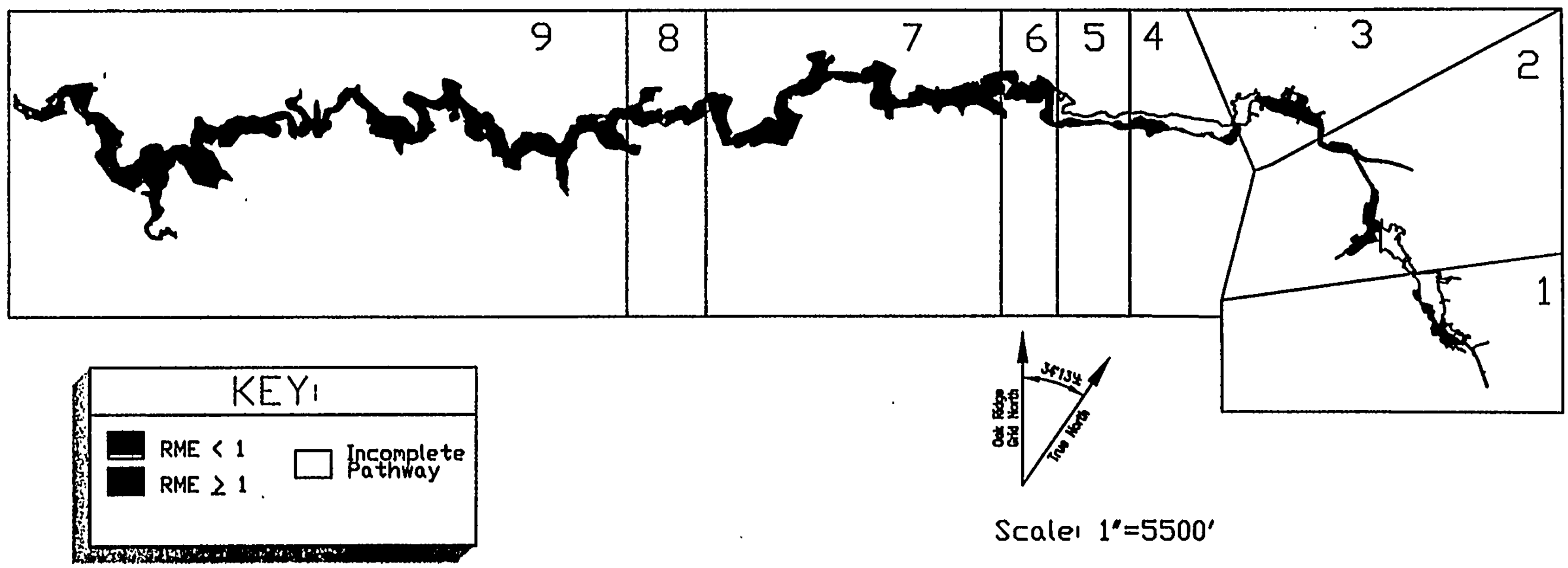
Fig. ES.13. Excess cancer risk for radionuclides for adults under future land use scenario.



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

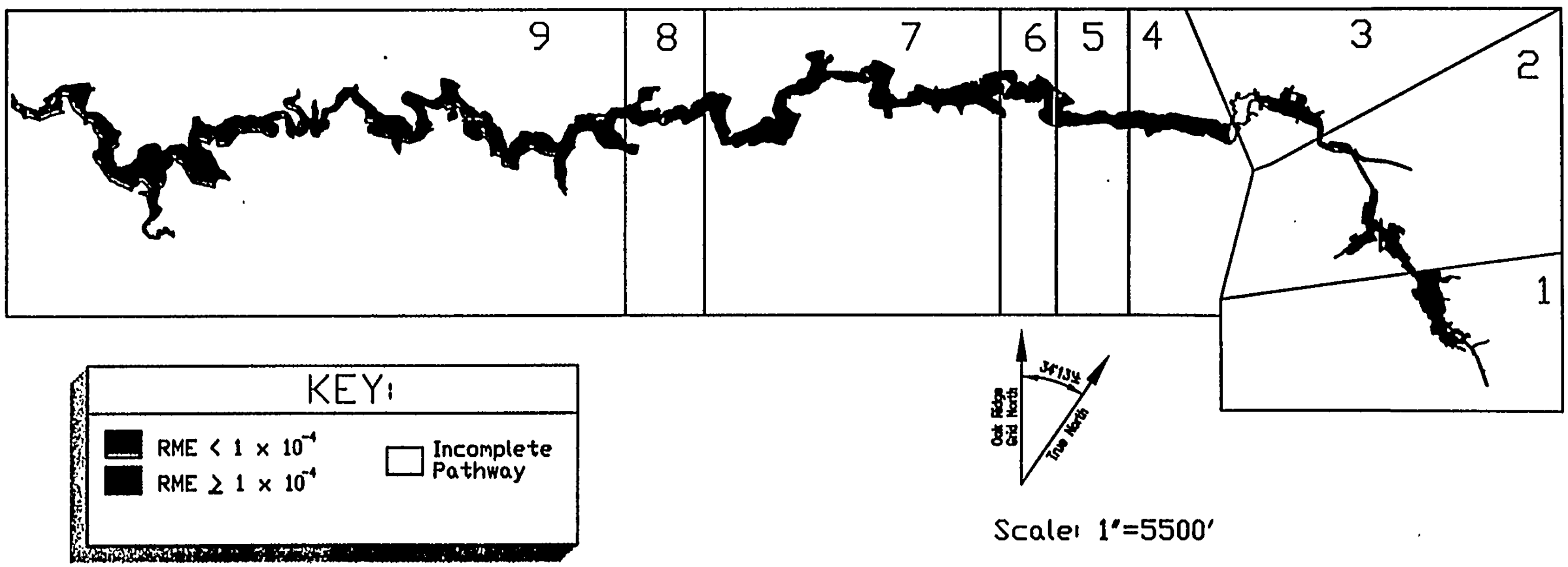
Fig. ES.14. Hazard index for noncarcinogens for children under current land use scenario.



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

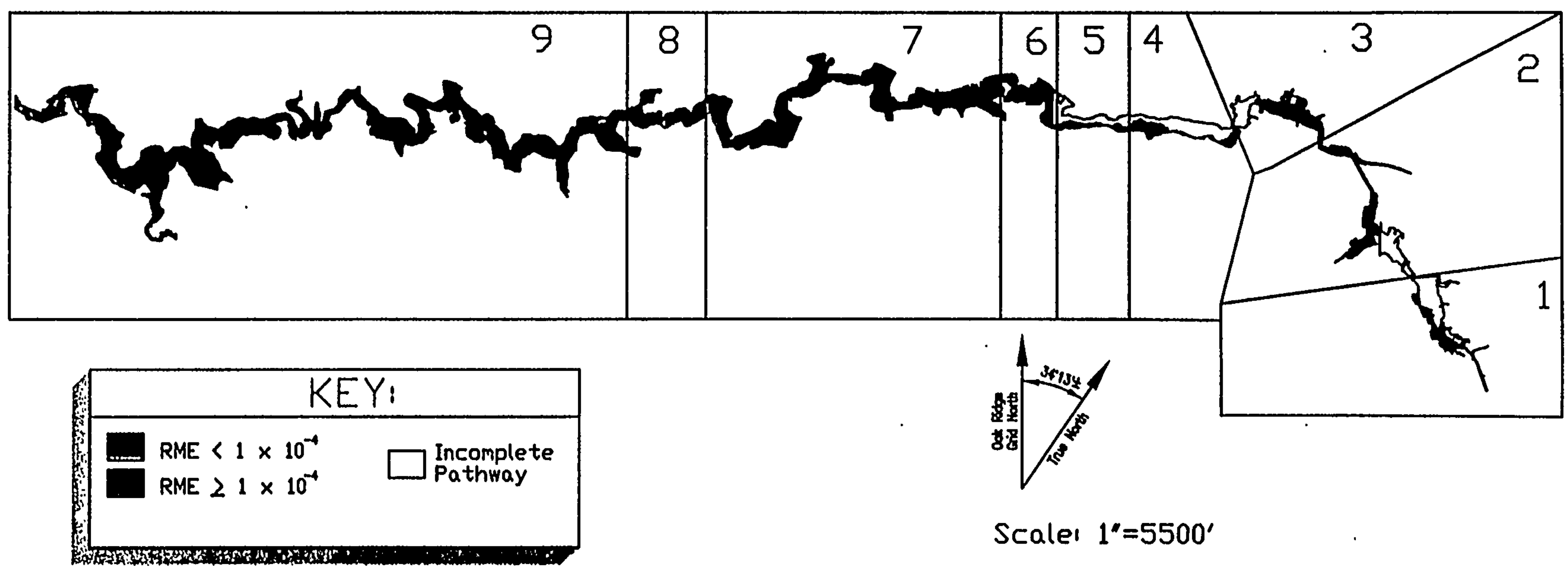
Fig. ES.15. Hazard index for noncarcinogens for children under future land use scenario.



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

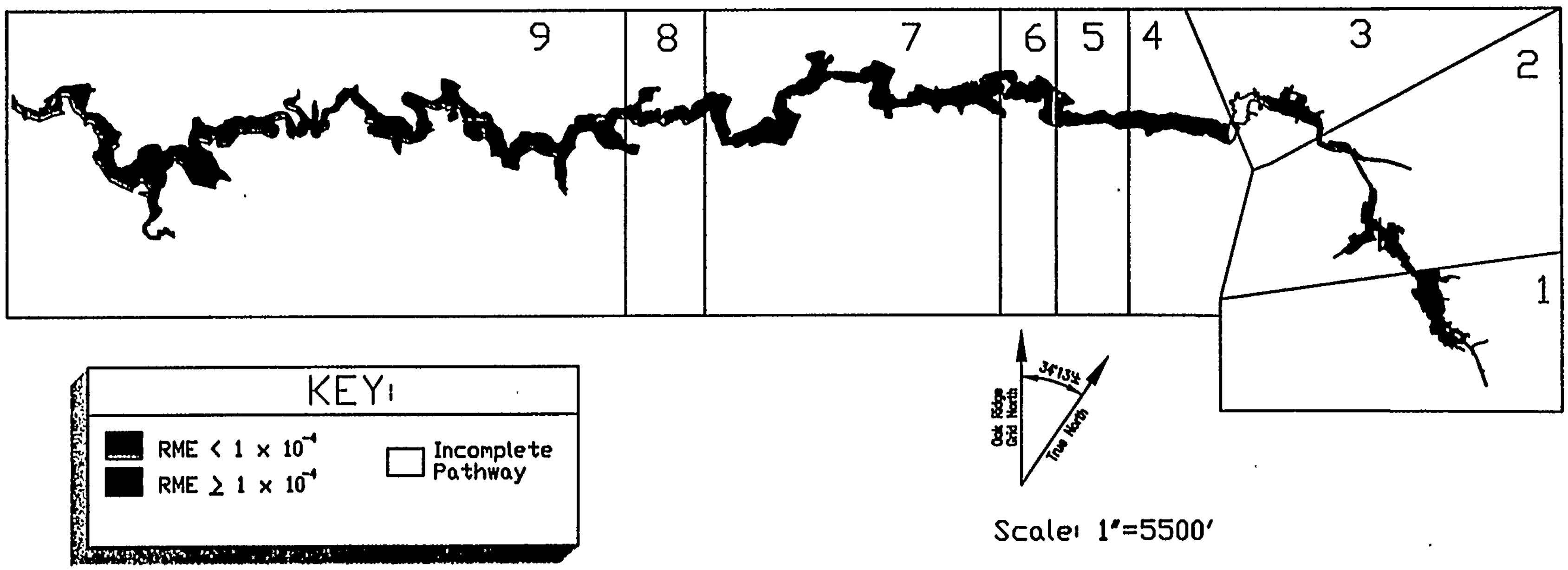
Fig. ES.16. Excess cancer risk for carcinogens for children under current land use scenario.



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

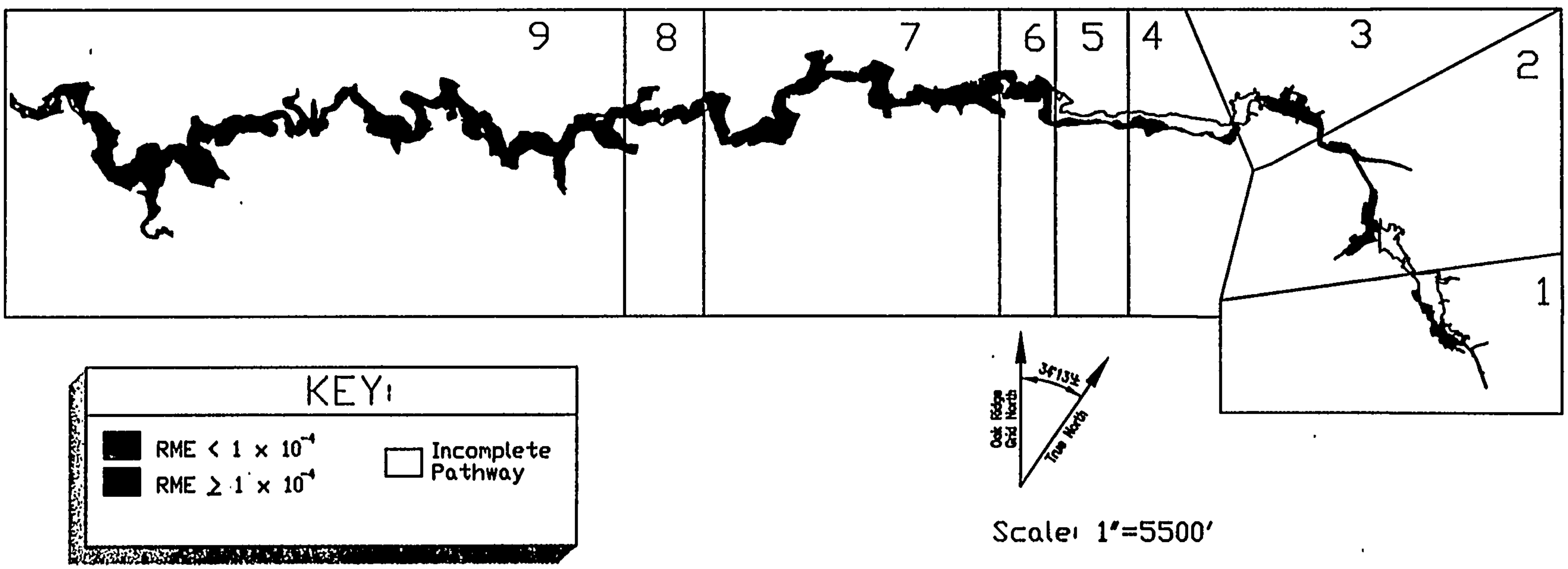
Fig. ES.17. Excess cancer risk for carcinogens for children under future land use scenario.



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

Fig. ES.18. Excess cancer risk for radionuclides for children under current land use scenario.



RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

Fig. ES.19. Excess cancer risk for radionuclides for children under future land use scenario.

For the current land use scenario, the risk estimates are consistently below or within EPA targets for most of the 271-ha (670-acre) floodplain. Figures ES.8, ES.10, ES.14, and ES.16 indicate that four areas, three of which are residential (in Segments 3, 6, and 8) and one of which is agricultural (in Segment 7), have both noncancer and cancer risks exceeding EPA targets. Risks for open land use are consistently either below or within EPA noncancer and cancer risk targets. In all cases, the pathway contributing the greatest risk is the foodchain (in particular produce), and the contaminants contributing the greatest risk are mercury (noncancer) and arsenic (cancer). All contaminants identified as COCs on the basis of risk estimates [e.g., individual substances with a hazard quotient (HQ) > 1 or a cancer risk > 10^{-4}] are associated with the food chain pathway only and occur only in those segments that include the food chain pathway (Segments 3, 6, 7, and 8).

Risks projected for future land use are above EPA targets in all segments, for both children and adults, as indicated in Figures ES.9, ES.11, ES.15, and ES.17. The exceedances are due primarily to food chain exposures and to the hypothetical use of groundwater as a future source of drinking water. In many cases, future risks are greater than current risks because of projected increases in exposure resulting from change over time to a more conservative land use (i.e., from open to residential). Exceedance of the EPA target for noncancer risks for future commercial land use, however, was entirely due to groundwater exposures. Noncancer and cancer risks for both children and adults exceeded EPA targets in all instances in which the food chain pathway was evaluated (i.e., all nine segments). COCs (e.g., individual substances with an HQ > 1 or cancer risk > 10^{-4}) identified on the basis of the produce pathway include arsenic, cadmium, manganese, mercury, silver, and vanadium. When the beef and dairy pathways are included, COCs also include Aroclor-1260, barium, chromium, copper, and selenium. For soil exposures in the future, only the noncancer target was exceeded, and only for Segments 1 and 4. The primary COC based on the risk estimates for soil exposures is mercury.

The primary health concern for both current and future soil exposures is noncancer effects related to exposures to mercury. When considering both current and future total risk estimates (e.g., summed across multiple substances), the soil pathway risks exceeded EPA targets at Segments 1, 3, 4, 5, and 8.

As noted above, EPA targets for both noncancer and cancer effects were exceeded anywhere the food chain pathway was considered (all nine segments). To put the food chain pathway in perspective, risks were estimated for the noncontaminated reference site at Hinds Creek using the same agricultural exposure assumptions that were used for the EFPC OU. Despite the absence of substantial mercury contamination in the Hinds Creek soils, the produce, beef, and dairy ingestion pathways all had risks exceeding EPA targets for both noncancer and cancer effects. For the produce and beef ingestion pathways, arsenic and manganese account for more than 90% of the risk. For the dairy ingestion pathway, arsenic, barium, copper, manganese, and zinc also account for over 90% of the risk. The magnitude of the food chain risk estimates for both EFPC and the Hinds Creek site is primarily attributable to the very conservative biotransfer factors that were used to model contaminant uptake from soil into the food chain.

No one is currently using groundwater in the vicinity of EFPC as a source of drinking water or is likely to do so in the future. However, this pathway was included in the BRA to comply with EPA requirements to comprehensively evaluate the groundwater pathway. Risks of hypothetical exposure to groundwater were evaluated separately for soil horizon wells and for water from the underlying bedrock. Both unfiltered and filtered samples were evaluated. Groundwater risks do not vary by segment because (1) the groundwater sample data were aggregated over the entire creek rather than by segment and (2) the same exposure assumptions were used for both the agricultural and residential scenarios. Commercial use of groundwater in the future results in risks in excess of EPA targets. The COCs for the groundwater ingestion pathway were arsenic, beryllium, manganese, and mercury.

Analysis of unfiltered groundwater data indicated levels of mercury and manganese exceeding EPA targets. A comparative risk assessment conducted using filtered groundwater samples resulted in lower hazard index (HI) scores overall as well as an HQ score for mercury that is lower by a factor of nearly 20. The HQ for manganese, however, remained >1 in the filtered sample. Other groundwater analyses showed that contaminant levels in groundwater from the soil horizon wells differed from those in groundwater from the underlying bedrock wells. Both noncancer and cancer risks are generally greater in the soil horizon wells, and this remains true when comparing unfiltered and filtered samples. Whether unfiltered or unfiltered, or from soil horizon or bedrock, the groundwater noncancer and cancer risks are all above EPA targets. Manganese is the primary chemical driving the elevated risk estimates for groundwater.

Risks were assessed for three areas along the SLB but were limited to soil exposures for open land use because commercial, agricultural, or residential land use is considered unlikely within the sampled portions of the SLB. Little or no change in land use was assumed for the SLB over time, and exposures at the SLB do not overlap those considered at EFPC. All of the noncarcinogenic or carcinogenic risk estimates for the SLB are within or below EPA targets. All HIs are <1, and the greatest combined cancer risks are on the order of 10^{-6}.

Risk characterization for exposures to lead from the EFPC OU required an alternative approach in which lead uptake into children's blood is estimated. EPA has developed a computer program to evaluate blood lead uptake in children less than 6 years old, the most sensitive receptors of lead exposures. Under current land use assumptions, only Segments 3, 6, 7, and 8 include exposures to children less than 6 years old.

None of the blood lead levels associated with current exposure at any of these segments approach the EPA target for blood lead levels. When considering future exposures, blood lead levels are generally within EPA targets. For children residing at Segments 3, 4, 5, and 8, the target was exceeded only when soil and groundwater exposures were combined. This is a marginal exceedance and includes soil, unfiltered groundwater, and built-in exposures from air and dietary sources of lead that are not related to the EFPC OU. Soil exposures did not approach the target when considered independently of groundwater exposures. When risk assessment was conducted using data from the underlying bedrock (instead of the soil horizon wells), blood lead levels did not exceed EPA targets. Only unfiltered groundwater exposures are associated with blood lead levels exceeding the EPA target, and the remaining exposures are well below the EPA target. As an additional point of comparison, the soil lead concentrations at each segment fall substantially below EPA soil cleanup guidelines for lead.

Tier III. The third tier, or probabilistic risk assessment, focused on exposure pathways that contributed the most to the overall risk, including inadvertent ingestion of soil, the produce ingestion pathway, and the hypothetical ingestion of groundwater. The outcomes of the Monte Carlo simulation include both receptor groups (adult and child) for each pathway and for both current and future land use. For the soil-related pathways (soil and produce ingestion), results are presented only for Segment 4. An illustrative uncertainty analysis for the soil pathways is presented for the segment with the highest observed soil concentration in Sect. 5 of this RI report. The uncertainty analysis is presented only for the single segment because the exposure assumptions for the residential and agricultural scenarios are the same across land use segments. The only difference between segments is the exposure point concentrations. Therefore, an analysis of a single segment can be used to illustrate the magnitude of uncertainty in the risk estimates.

The RME point estimates are generally quite conservative and fall within the upper tail of the probability distributions. In some cases, the RME estimates exceed the 95th percentile values. Of particular concern are the conservative point estimates used for the food chain biotransfer factors (BTFs). These factors predict the biotransfer of each contaminant from soil to plant tissue. These data and the results of an experimental garden study suggest that the BTF for mercury obtained from the literature and used in the BRA is probably one to two orders of magnitude too high.

The Tier II and III results, the results of the garden uptake study, and the risk assessment of Hinds Creek all indicate that there is considerable uncertainty in the risk estimates associated with the food chain pathways. Given this and the fact that very limited agricultural or gardening activity is occurring along EFPC (or is likely to occur in the future), the results for the food chain pathways should be considered only as hypothetical, "high-end" or "bounding" estimates of risk to human health.

Although risk estimates for the groundwater ingestion pathway exceed the target range established by EPA, this pathway does not present a substantial risk to human health. No one is currently using groundwater in the vicinity of EFPC as a source of drinking water or is likely to do so in the future because all residents are provided with city water. Even though contaminant concentrations were considerably reduced in filtered samples, the overall HI score for the pathway is still > 1 by a small margin. This is principally due to dissolved concentrations of manganese. The presence of arsenic is responsible for the excess lifetime cancer risk estimate exceeding 10^{-4}. Manganese is present in background soils at levels comparable to that in EFPC soils and, therefore, occurs naturally in this geographic area. Although levels of arsenic in floodplain soils exceed those at the reference location, the presence of arsenic in groundwater cannot clearly be attributed to releases from the Y-12 Plant. The results of the Tier III analysis of groundwater indicate a range of uncertainty of less than an order of magnitude based upon variability in exposure assumptions.

The results of the EFPC BRA indicate that RME estimates of risks of adverse noncarcinogenic effects associated with inadvertent ingestion of soils exceed the EPA target range at locations throughout the floodplain. The risk is due primarily to mercury concentrations in soil, with cadmium and arsenic contributing to a lesser degree. Concentrations of mercury, cadmium, and arsenic were significantly higher than those found at the noncontaminated reference site. The Tier III assessment demonstrates that there is less than an order of magnitude of uncertainty in the RME point estimates for soil ingestion.

The risk from the soil ingestion pathway was estimated using an RfD for mercury of 0.0003 mg/kg per day. The RfD used was based on toxicity testing using soluble mercury species (mercuric chloride) in laboratory animals, rather than the less soluble forms (mercuric sulfide) believed to predominate in EFPC floodplain soils. The BRA conservatively assumed that all mercury in EFPC is present in its most bioavailable form.

ES.3.2 Ecological Risk Assessment

The purpose of the EFPC ecological BRA was to determine baseline levels of risk to various animal and plant populations and habitats in EFPC. This information was then used to determine whether contaminants pose an imminent and substantial danger to the health of various ecological resources and whether and where site remediation may be needed. The ecological risk assessment (ERA) process differs from the human health risk assessment process in that it focuses on populations and communities rather than on individuals. Individuals are addressed only if they are protected under the Endangered Species Act. Rather than attempt to examine every species living in and around EFPC, a weight-of-evidence assessment was conducted to determine the effects of contaminants on indicator species (representative species from each major aquatic and terrestrial habitat) and to extrapolate from them to project the overall effects of other and unmeasured contaminants on the ecosystem.

The ERA, as described in *Framework for Ecological Risk Assessment* (EPA 1992c), involves four basic steps occurring in three primary phases (Fig. ES.20): (1) problem formulation, (2) exposure characterization, (3) effects characterization, and (4) risk characterization. These interrelated activities are defined as follows.

Problem formulation establishes the goals, breadth, and focus of the assessment. It provides a preliminary characterization of (1) chemical and physical stressors present in the ecosystem, (2) the components and especially indicator organisms of the ecosystem likely to be at risk, and (3) the potential ecological effects. This preliminary characterization, along with a selection of assessment and measurement endpoints, is used as the basis for developing a conceptual model of stressors, components, and effects. Assessment endpoints are values that, if exceeded, suggest the need for remediation.

Exposure characterization evaluates the interactions of the stressors with the ecosystem attributes and describes the biotic and abiotic ecosystem attributes, along with the route, magnitude, frequency, duration, trend, and spatial pattern of exposure of each indicator population or habitat component in relation to a chemical or physical stressor.

Effects characterization evaluates the ecological response to chemical and physical stressors in terms of the selected assessment and measurement endpoints. Depending on the parameters of exposure, it results in a profile of response to stressors at concentrations or doses or other units of stress to which populations and habitats are exposed. Data from both field observations and controlled laboratory studies are used to evaluate ecological effects.

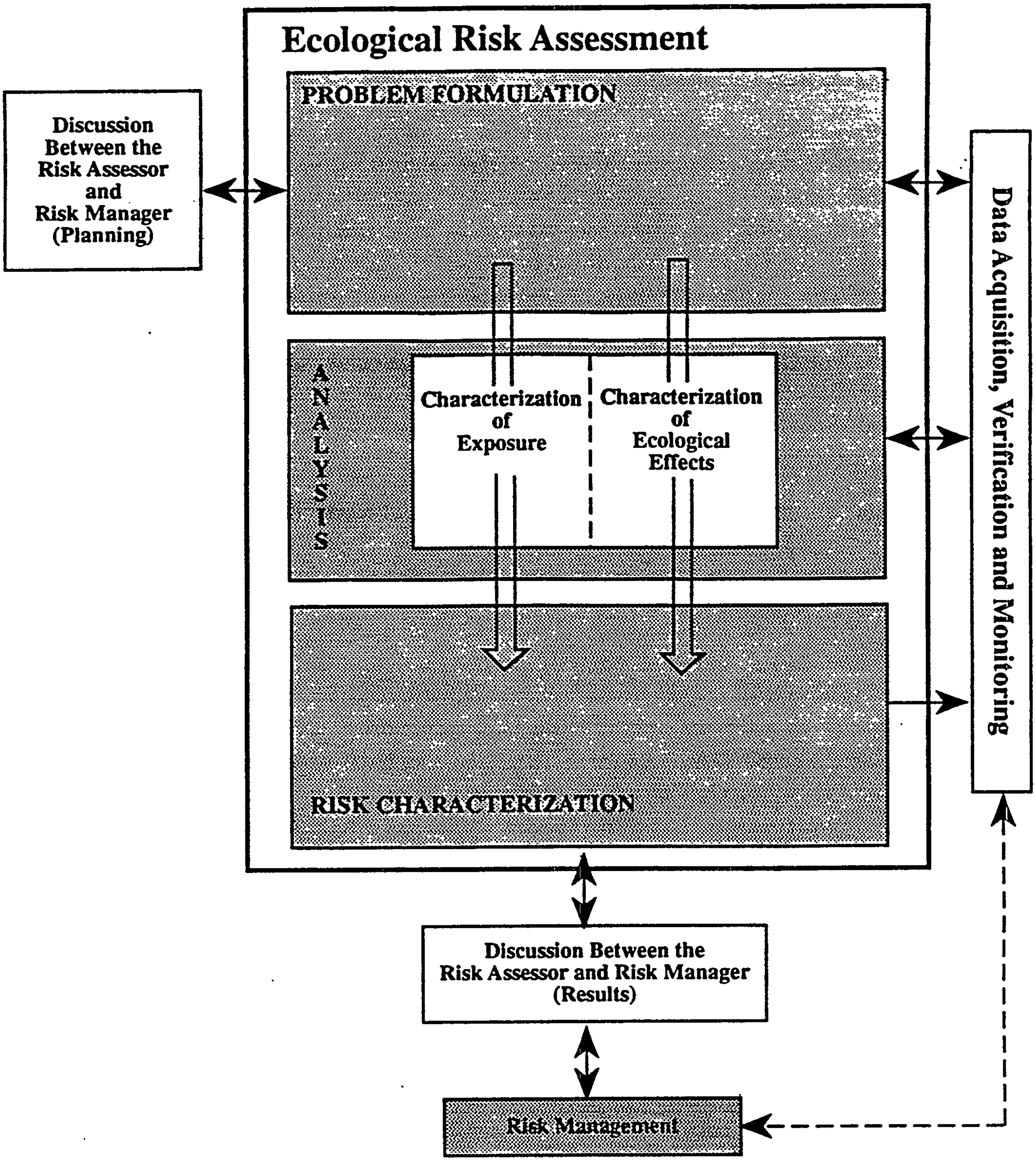


Fig. ES.20. Framework for three-phase, four-step ecological risk assessment (*Source:* EPA 1992c).

Risk characterization integrates the effects of exposure and stressor response on indicator populations or habitat components, using risk quotients (a ratio of exposure value to effect value); interprets these data according to the weight-of-evidence approach; and then further interprets the ecological significance, including the potential for ecosystem recovery.

ES.3.2.1 Problem formulation

Critical to the performance of an ecological assessment is the early establishment of goals and objectives for the study. For the EFPC ERA, seven primary goals were developed, along with 12 associated assessment/measurement endpoints (Table ES.5). These goals reflect government environmental policy, such as NEPA compliance or ARARs attainment, as well as important characteristics of the specific populations and habitats within the EFPC OU that are potentially at risk.

Also important to the initial formulation of the problem and to the development of conceptual models and sampling plans is a thorough understanding of the historical information on contaminant types, locations, and the respective ecological receptors of these contaminants. Contaminants within the EFPC environment have been described and characterized in several previous studies (Van Winkle et al. 1984; TVA 1985; Gist 1987; Carmichael 1989; Loar 1992; Hinzman 1992; Turner et al. 1992 and Appendix Q). The ORAU (Gist 1987) study, conducted between 1983 and 1987, included surveys for mercury in the surface soil along 100-m transects across the floodplain from the Y-12 Plant to the Oak Ridge city limits in Roane County, grid sampling for mercury within a highly contaminated floodplain property, sampling for mercury from vertical profiles at various sites, and sampling of selected lawns and gardens in Oak Ridge. Vegetation, sewage sludge, groundwater, and two road-killed deer were sampled and analyzed for radionuclides, mercury, and other metals. The TVA study, performed during 1984, sampled soils, sediments, surface water, fish, amphibians, crustaceans, and reptiles, which were then analyzed for mercury and other metals, radionuclides, organics, pesticides, and PCBs. The Y-12 Plant BMAP, begun in 1985, performs semiannual sampling of natural populations of fish, which are then analyzed for mercury, PCBs, and cesium (Loar 1992; Hinzman 1992). Bioaccumulation studies of PAHs and PCBs have been conducted annually using caged clams. The USGS conducted a survey of groundwater contamination by metals, radionuclides, and organics in 1987 (Carmichael 1989). This study sampled 14 shallow-aquifer wells at sites of known mercury contamination within the floodplain. Other one-time studies include the assessment of mercury and strontium in small mammals by Energy Systems and a 1982 rapid assessment survey of mercury contamination in multiple media (i.e., sediments, mosses and liverworts, grasses, and fish) (Van Winkle et al. 1984).

Table ES.5. EFPC ERA endpoints

Goals	Assessment endpoint	Measurement endpoint
1. Conservation of threatened, endangered, and rare species and their critical habitats	1a. No harm to any threatened and endangered species and their critical habitat of the EFPC floodplain	1a. Surveys of presence/absence of species and their habitats on the EFPC floodplain
	1b. Maintenance of plant community composition and/or structure required for rare plant/animal and support species	1b. Abundance and distribution of plant/animal species that would support threatened, endangered, and rare species
	1c. Exposure of threatened and endangered species to biomagnifiable contaminants through the food chain	1c. The body burdens of contaminants in selected species representative of lower trophic levels of aquatic and terrestrial food chains
2. Protection of migratory birds	2a. No killing or harming of migratory birds as a result of exposure to site-specific stressors	2a. Contaminant concentrations in selected migratory birds and weight-of-evidence data
3. Preservation of wetlands	3a. The presence and structure/function of wetlands in relation to contaminants	3a. Wetlands survey and their contaminant levels, if any, on the EFPC floodplain
4. Existence of a fish community indicative of undegraded conditions	4a. Fish community in which the proportion of species tolerant of degraded water quality is $<30\%$	4a. Proportion of tolerant species at the site
5. No adverse effects from contaminants to aquatic indicator organisms and/or predators that feed on them	5a. Ratio of contaminant concentrations in surface water to water quality criteria for protection of aquatic life ≤ 1	5a. Contaminants in surface water
	5b. Aquatic indicator organisms contaminant body burden ratio to toxicological effects levels ≤ 1	5b. COPC concentrations in whole-body samples of aquatic indicator species
	5c. Fish contaminant body burden ratio to levels protective of piscivorous biota ≤ 1	5c. COPC concentrations in whole-body samples of aquatic indicator prey species
6. Existence of terrestrial animal community indicative of undegraded conditions	6a. Terrestrial animals with diversity, abundance, and distributions indicative of undegraded conditions resulting in $\geq 20\%$ decrease compared to the reference	6a. Population abundance and distribution by habitat

Table ES.5. (continued)

Goals	Assessment endpoint	Measurement endpoint
7. No adverse effects from contaminants to terrestrial indicator organisms and/or predators that feed on them	7a. Ratio of contaminant body burdens in terrestrial indicator species to toxicological effects levels ≤1	7a. COPC concentrations in whole-body samples of terrestrial indicator species
	7b. Ratio of contaminant body burdens in terrestrial indicator species to levels protective of terrestrial predators ≤1	7b. COPC concentrations in whole-body samples of terrestrial indicator prey species

The conceptual model for the EFPC ERA is these early studies, which indicated the existence of two major exposure sources within EFPC and its floodplain. Water effluents from the Y-12 Plant continually expose aquatic organisms to contaminants and can contribute to the exposure of terrestrial organisms during floods through direct contact with biota or through deposition of water-borne contaminants on floodplain vegetation and soil. The second source, previously contaminated floodplain soil, also contributes to the exposure of terrestrial organisms through direct contact, inhalation, and ingestion and to exposure aquatic organisms through erosion or scouring and redeposition of soil into EFPC. Direct exposure routes exist through the air, shallow groundwater, surface water, instream sediments, and soil. Indirect exposure occurs through ingestion of contaminated forage or prey. Conceptual models of the food web relationships for selected EFPC biota are depicted in Fig. ES-21 for aquatic biota and Fig. ES-22 for terrestrial biota. These show how contaminants in biotic media can be transferred to predators.

ERA Sampling Locations and Sampling Design. The area in which organisms are exposed to contaminants is defined by both their home range in habitats and the distribution of contaminants. To facilitate evaluation of exposures in different EFPC habitats, the OU was divided into sections. The sections were arbitrarily based on the EFPC sampling grid; 17 sections were created, each comprising 1 km from west to east on the sampling map. The first section begins just below the confluence of EFPC with Poplar Creek, and section 17 is located at the beginning of the study area below Lake Reality. Within these 17 sections, a wide variety of surface water/sediment and soil/vegetation habitats was identified and mapped. For surface water, four distinct aquatic habitats were defined (runs, riffles, pools, and other); for the terrestrial habitats, 12 distinctions were made, including 4 forest categories, 5 field or relatively cleared habitats, and 3 developed/commercial settings. Most of the terrestrial habitats were found to be bottomland hardwoods, while the most prevalent aquatic habitat was the stream runs. Seventeen wetlands were found to exist in or near the floodplain; some have mercury contamination, but there is no visible evidence of negative impact on the wetlands.

Locations of the ecological sampling sites for the EFPC ERA were chosen to gain maximum information on EFPC biota and their physical environment and to allow comparison and contrast with historical data. The six aquatic sampling sites, as shown in Fig. ES.23, were selected to represent a gradient of biological and physical conditions. Site 1 is located in Pine Ridge Gap near the outfall from Lake Reality, and Sites 2 and 3 (NOAA and Bruner's Center sites) are located near areas previously identified as having high mercury concentrations in soils. Coordination with BMAP sampling personnel ensured that no adverse effects occurred to these

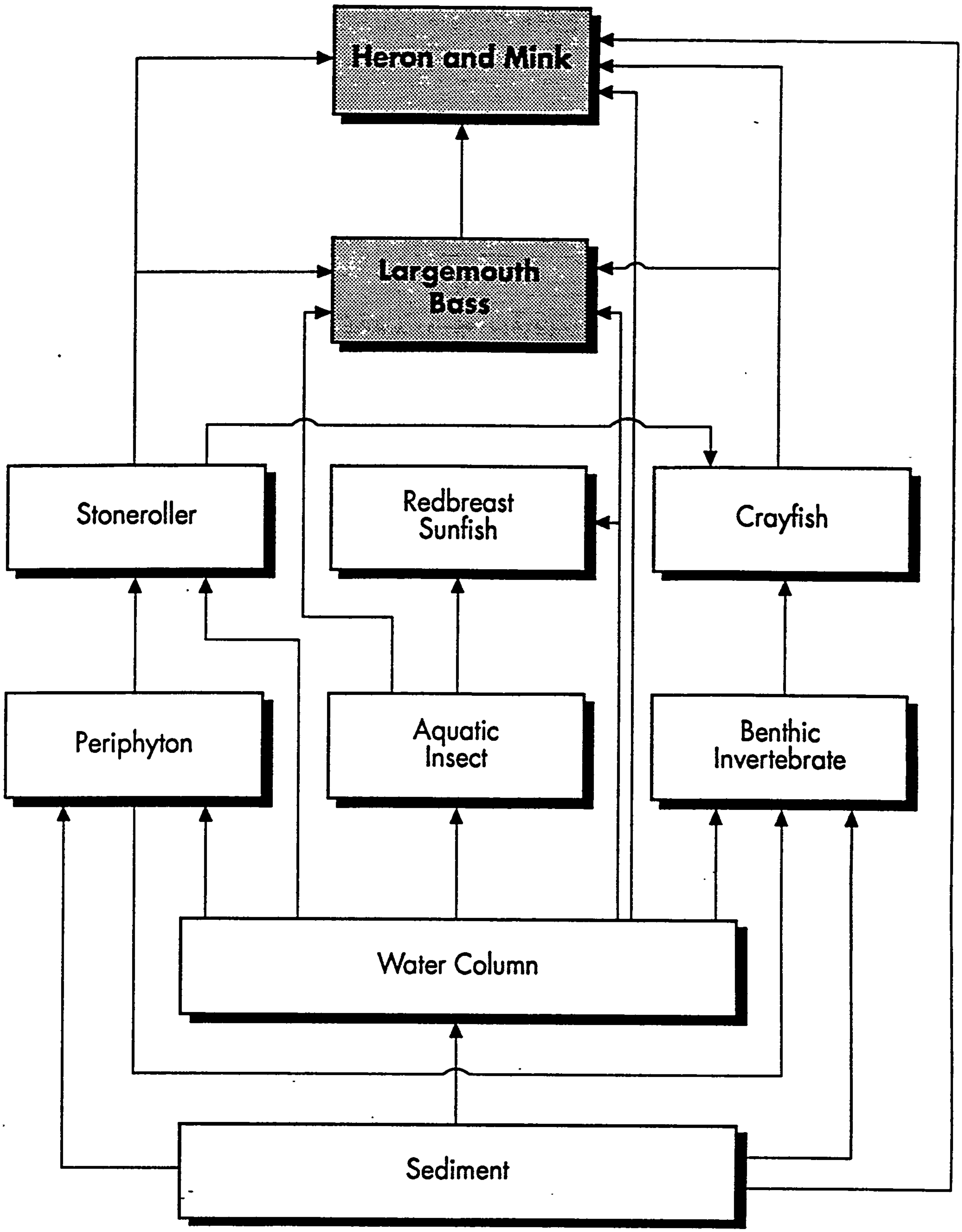


Fig. ES.21. Food web relationships of aquatic biota sampled (clear boxes) or modeled (shaded boxes) for EFPC ecological risk assessment.

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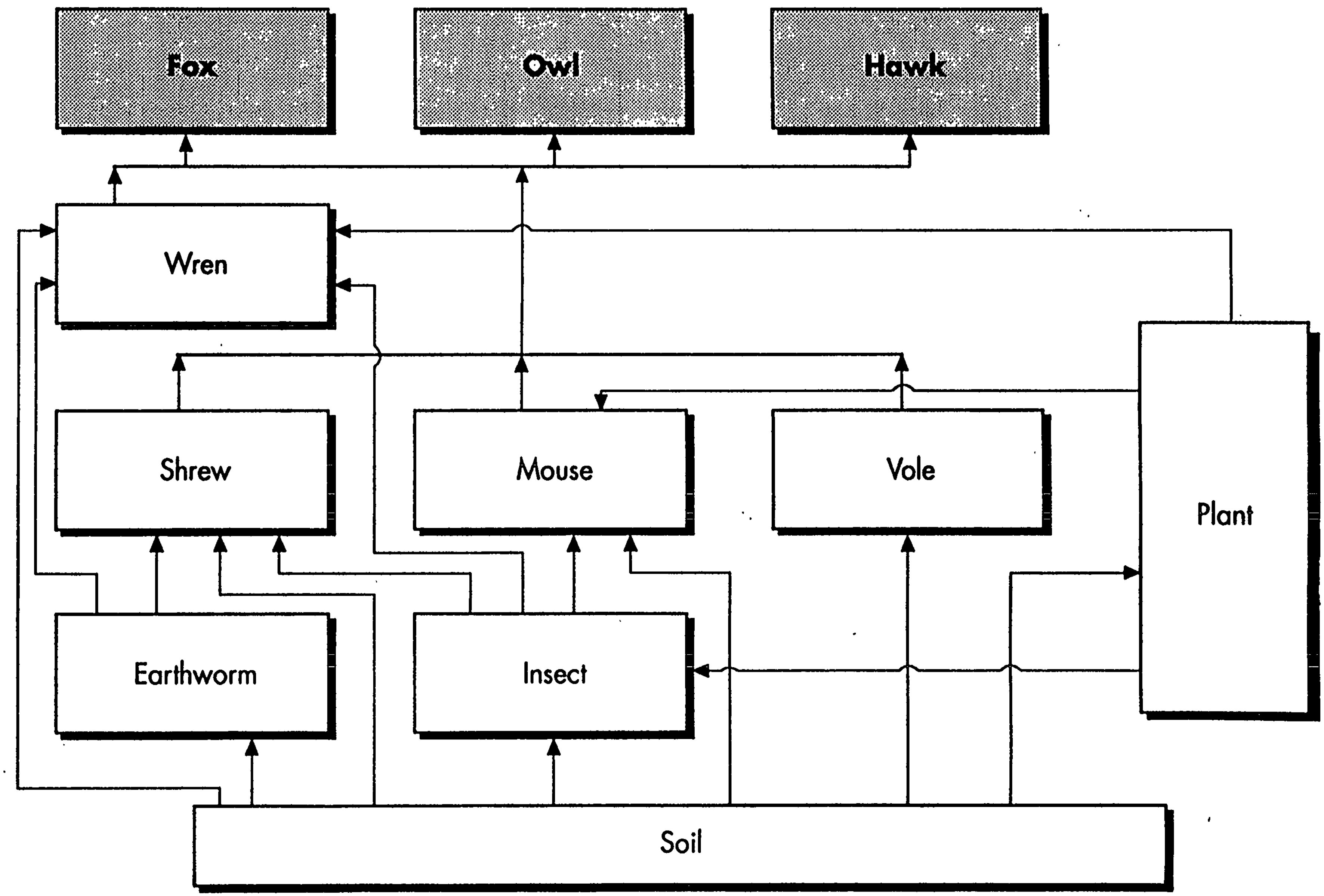

Fig. ES.22. Food web relationships of terrestrial biota sampled (clear boxes) or modeled (shaded boxes) for EFPC ecological risk assessment.

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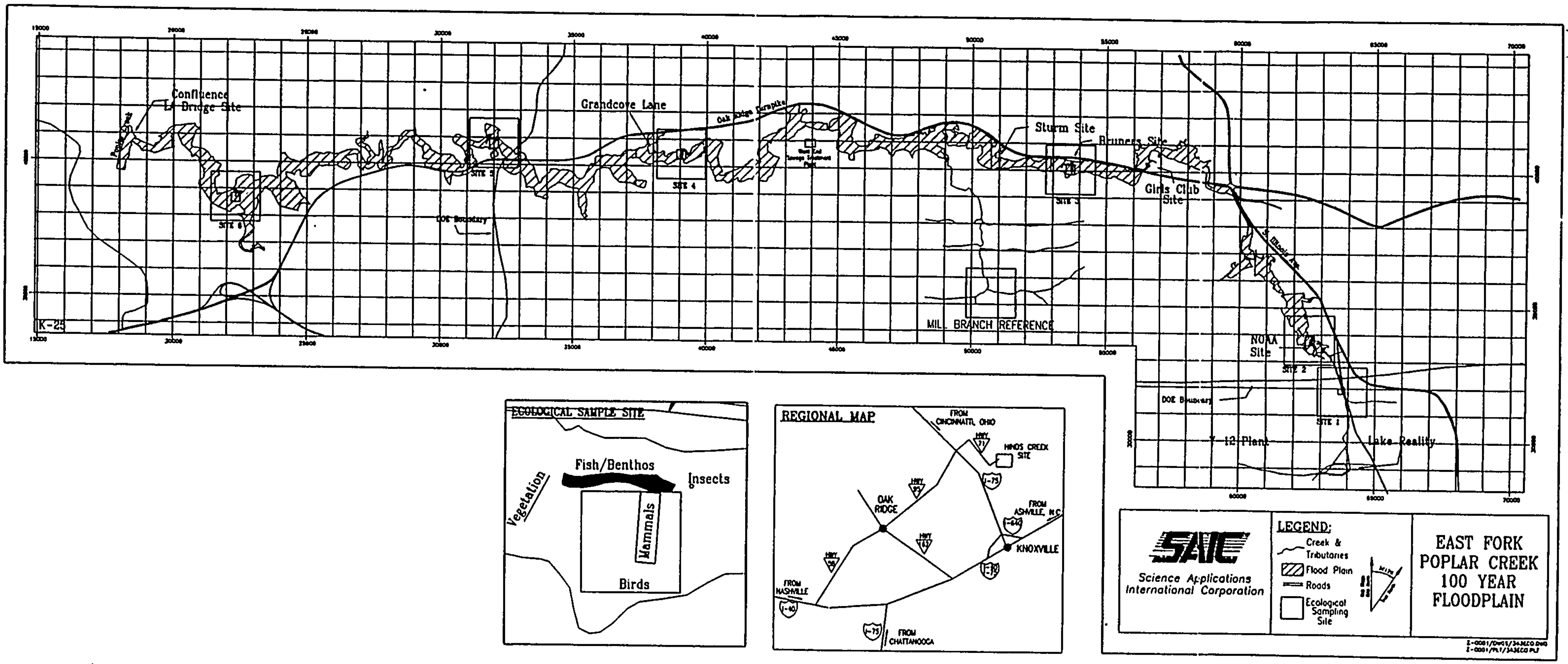

Fig. ES.23. Map of EFPC ecological sampling sit

sampling locations during the RI sampling and facilitated comparisons with the BMAP results. Site 3, or the Burner's site, also serves as an upstream reference for impacts of the Oak Ridge Sewage Treatment Plant. Site 4, located below the plant outfall, was selected to enable the assessment of impacts of the treated municipal wastewater on the biota. The last two sites are located in the lower reaches of EFPC; Site 5 is upstream from Bear Creek, while Site 6 is downstream. Where possible, terrestrial biota were sampled at the same sites. Sites were also selected to allow easy as opposed to difficult access for sampling equipment and personnel.

Because EFPC originates on the Y-12 Plant site, an aquatic reference site located upstream from the EFPC OU could not be obtained. Thus, a site on Hinds Creek near Norris, Tennessee, was selected as the aquatic reference site (Figs. ES.24 and ES.25). The Hinds Creek site was selected as the aquatic reference site because the available information on surface and subsurface geology, hydrology, anthropogenic contaminant sources, and residue analyses in fish all indicated that this site most closely approximated the EFPC watershed. The similarity between the Hinds Creek and EFPC watersheds, coupled with the relative absence of anthropogenic contaminants at Hinds Creek, qualified the site as adequate for making comparisons with the EFPC OU. In addition, BMAP has been using a location in Hinds creek for its reference site for several years with a allows data comparability with this ERA investigation.

Site 6 on Mill Branch (Fig. ES.25), a tributary within the EFPC watershed, was selected as the terrestrial reference site. Several criteria were used in the selection process. All watersheds with known or suspected contamination were automatically eliminated from consideration, and an attempt was made to locate a site with similar vegetation. The Hinds Creek soil reference site was judged to be unsuitable for use as the terrestrial vegetation reference site because the vegetation surrounding the Hinds Creek site is all pasture, while most of the study sites along EFPC are forested. The Mill Branch site, like the Hinds Creek site, was believed to have received minimal anthropogenic chemical contamination. On this basis, the Mill Branch site was judged to be an adequate reference site for terrestrial fauna for comparisons with the EFPC OU. The location of the site within the EFPC watershed was also regarded as a positive factor. Despite the advantages of the Mill Branch site, however, its use as a reference site for terrestrial biota is somewhat limited by the fact that it supports a small, immature upland forest community rather than the many acres of mature bottomland hardwood communities typically found along EFPC. No noncontaminated reference site for terrestrial vegetation was found that was similar to the EFPC floodplain with respect to species composition and therefore suitable for direct comparisons.

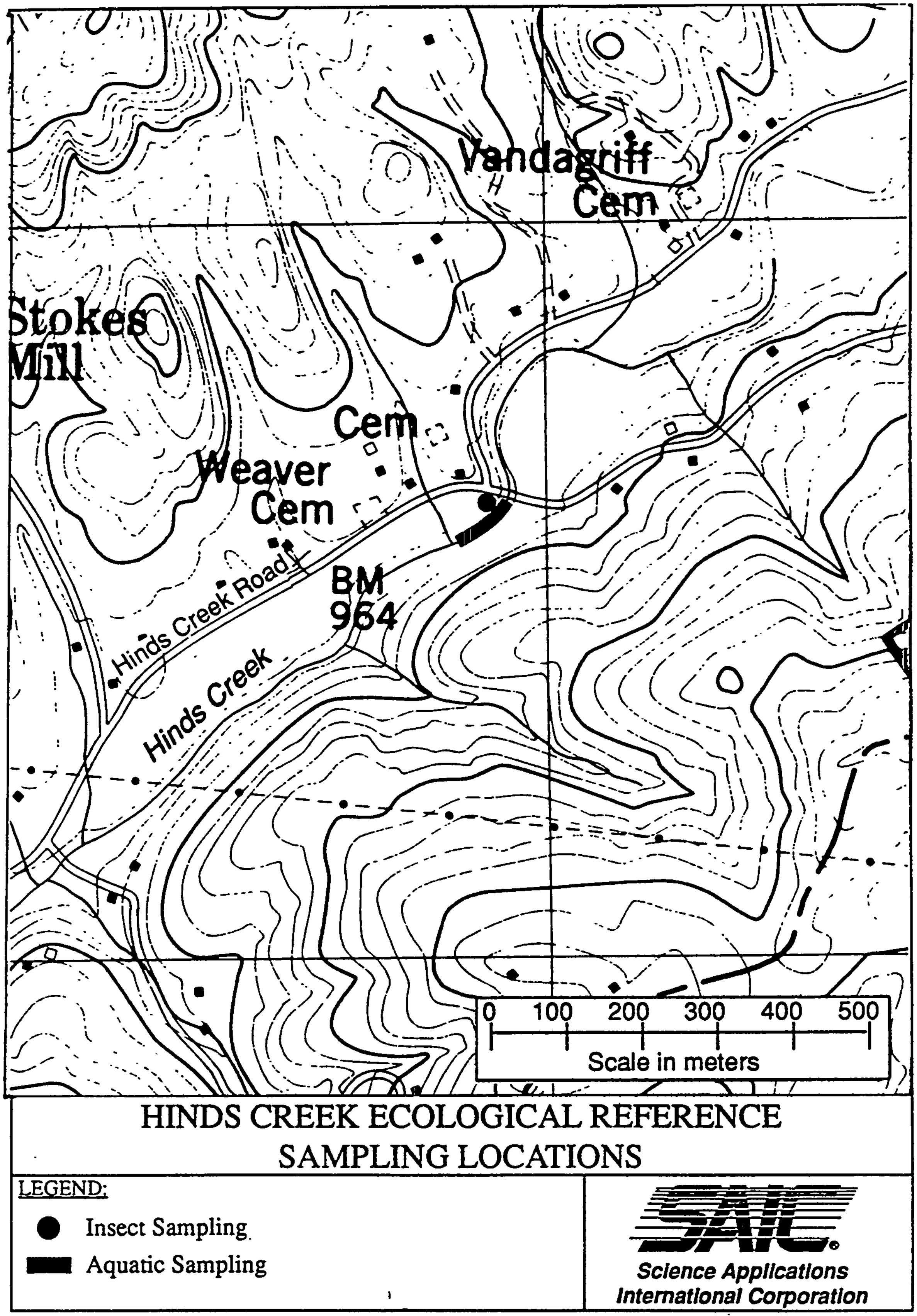

Fig. ES.24. Hinds Creek ecological reference sampling sites.

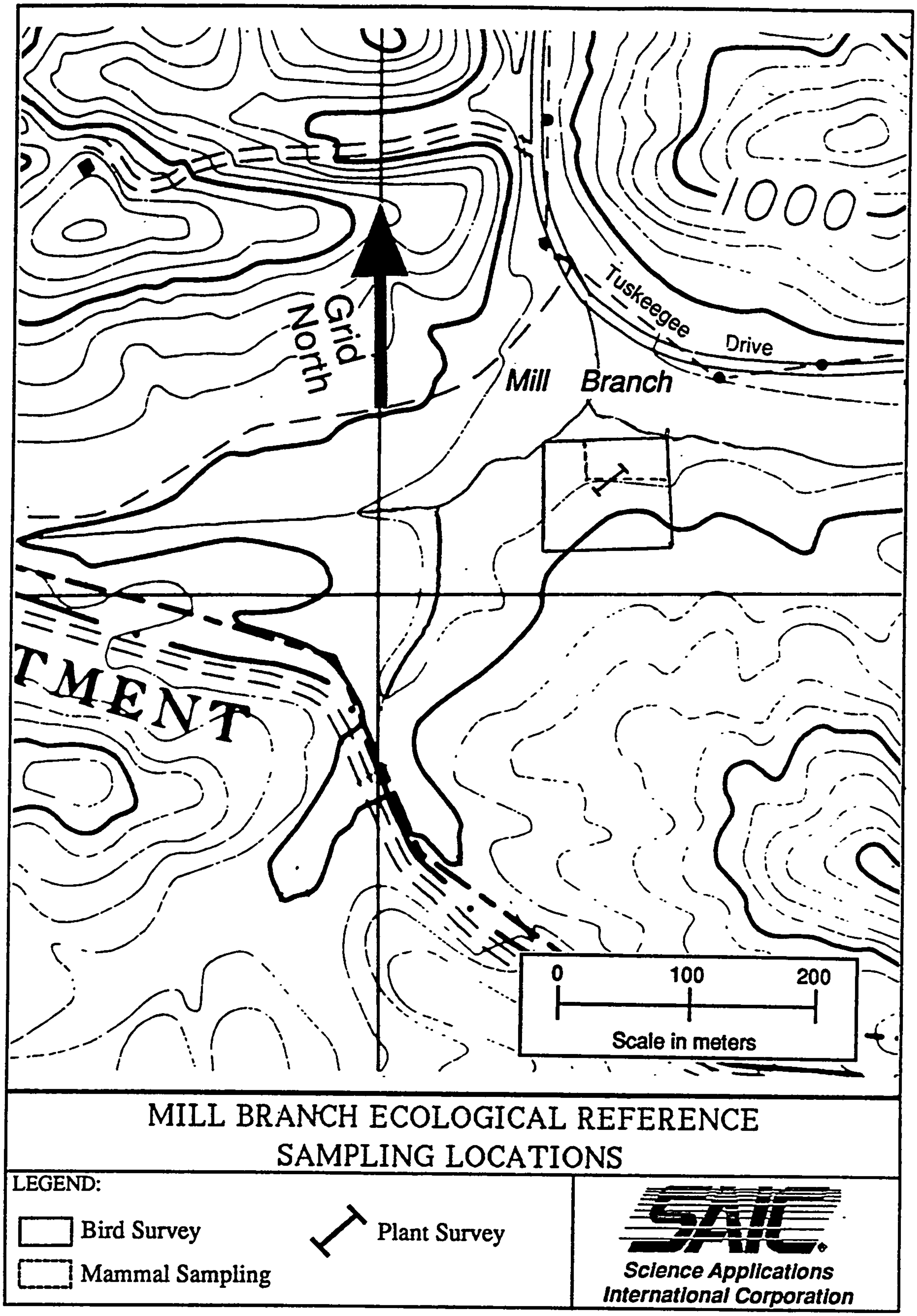

Fig. ES.25. Mill Branch ecological reference sampling sites.

In addition to the aquatic and terrestrial species sampling conducted at the EFPC and reference sites, grasses and browse were taken at three sites and browse was taken at one site along the EFPC floodplain. Grasses and browse were also sampled at the Hinds Creek Reference site. At each EFPC site, a sample of grass or browse was taken at the creek edge and at a distance of 100 m from the creek. Beets, kale, and tomatoes were grown at a special vegetable plot located on the floodplain and a reference location outside the floodplain, and the plant roots, leaves, and fruits were sampled. These vegetation measurements supplemented the historical studies on woody species in EFPC. Also important to the ERA were the environmental sampling results for soils, sediments, surface water, groundwater, and air discussed earlier in this Executive Summary.

Indicator species were selected by a process, outlined in *Habitat Evaluation Procedures ESM 102* (FWS 1980), that relies on groups of organisms that occupy a common environmental resource (e.g., sediment, water column, vegetation). The indicator organisms were used as surrogates for the groups of organisms mentioned in the assessment and measurement endpoints. It was judged to be impractical to directly measure and/or model exposure, effects, and risk to all the species represented by the assessment/measurement endpoints. Factors included in the selection of indicator species included their presence in EFPC, ability to obtain measurable responses, adequate sample size, phenology, and small home range within the EFPC OU to ensure exposure. In addition, some species that did not necessarily meet these criteria, such as threatened or endangered species and other species of concern (e.g., migratory birds), were selected because they were important as assessment endpoints. Species of concern included those that are vital to ecosystem energy and biogeochemical cycling, are particularly susceptible or sensitive to contaminants, and are specific bioaccumulators. Also, plants were selected to represent the lower trophic levels in the food chain to allow modeling up the food chain.

Aquatic indicator species included fish [common stonerollers (*Campostoma anomalum*), redbreast sunfish (*Lepomis auritus*), largemouth bass (*Micropterus salmoides*)], sediment-dwelling invertebrates (benthic macroinvertebrates and crayfish), and periphyton (algae and heterotrophic microbes) attached to submerged surfaces in the substrate. Terrestrial indicator species included small mammals [short-tailed shrew (*Blarina brevicauda*) and white-footed mouse (*Peromyscus leucopus*)], birds [Carolina wren (*Thryothorus ludovicianus*) and great blue heron (*Ardea herodias*]), invertebrates (earthworms and adult terrestrial insects) living in or on the soil, and plants (grasses and vegetables). These aquatic and terrestrial indicator species were targeted for population surveys and body burden analyses to represent the key exposure points in the EFPC ecosystem. A summary of the types of measurements and analyses conducted as part of the ERA is provided in Table ES.6.

Table ES.6. Measurements made for the EFPC ERA

Matrix sampled	Population measures			Contaminant concentration	Colonization rate	Growth rate
	Relative abundance	Biomass	Diversity			
Aquatic						
Fish	X	X	X	X		
Benthic macro-invertebrates	X		X	X		
Periphyton					X	X
Water				X		
Sediments				X		
Terrestrial						
Small mammals	X	X	X	X		
Birds	X		X	X		
Insects	X	X	X	X		
Earthworms	X		X	X		
Vegetation	X		X	X		
Soil				X		

The field investigations were conducted from the late summer of 1991 through the late summer of 1992. The aquatic ecosystem is considered to be representative under conditions of stable base flow. The late summer and early fall were selected for intensive field surveys to satisfy the need for low rainfall conditions typically experienced during these seasons. Because of the present knowledge of the area, abundance of existing biological data on EFPC, and the schedule-driven constraints for the EFPC RI, as specified in the FFA, no initial field screening was performed. The schedule and funding level allowed the one-season approach. In addition, fall sampling allowed data comparability with BMAP's fall sampling of fish and benthic macroinvertebrate communities. Communication and coordination with BMAP sampling personnel ensured that no adverse effects occurred to the BMAP sampling locations or BMAP's long-term studies. Without this communication with BMAP personnel, sampling crews could have inadvertently physically damaged or sampled existing riffles used by BMAP for their benthic macroinvertebrate studies, thereby potentially leading to benthic community data that were not representative of the site(s). Data from the BMAP—a multi-season and multi-year study—were used to round out the temporal aspects of the characterization.

ES.3.2.2 Exposure characterization

Exposure environments in EFPC and its floodplain consist of a heterogeneous mixture of flow regimes, streambed conditions, and terrestrial habitats varying from commercial through agricultural to woodland. Surface water is a primary medium by which aquatic organisms are exposed to contaminants currently being released to EFPC via surface water from the Y-12 Plant and to contaminants in floodplain soils that are transported via erosion, surface runoff, and shallow groundwater. Soil is the primary medium of exposure for terrestrial biota. Stream sediments are a second major exposure route for benthic invertebrates and for terrestrial consumers by way of flood deposits on soil and vegetation. In both aquatic and terrestrial communities, indirect exposure of organisms via the food chain is important. Methylation/demethylation of mercury in sediments and stream water and biodegradation of organic contaminants are the most important chemical transformations. Methylmercury is assumed to be the predominant form of mercury in aquatic biota. In the absence of remediation, the exposures of EFPC communities to contaminants are not expected to change dramatically from those levels identified through the Phase Ia and Ib sampling of the soils, sediments, surface, and groundwater along EFPC and the SLB. Table ES.7 summarizes the expected dominant mode of exposure for the EFPC ecosystem, based on the identified media of exposure and the respective indicator species.

Table ES.7. Dominant mode of exposure of indicator organisms to contaminated source media in EFPC

Indicator biota	Medium				
	Surface water	Instream sediment	Groundwater	Soil	Biota
Fish	D	D/I	I	*	D
Benthic invertebrates	D	D	I	*	D
Aquatic insects	D	D	I	*	D
Crayfish	D	D	I	*	D
Periphyton	D	D	I	*	*
Small mammals	D	*	I	D	D
Birds	D	I	I	I	D
Terrestrial insects	*	*	I	D	D
Earthworms	*	*	I	D	*
Plants	D	D	I	D	*

D = Direct exposure
* = Incomplete pathway or considered negligible
I = Indirect exposure

Exposure conditions of the indicator species were characterized by implementing the ERA sampling plan and incorporating historical data where appropriate to fill in data gaps. The ERA sampling results are summarized in Table ES.8 for aquatic biota and in Table ES.9 for terrestrial biota.

COPCs in biota were screened to eliminate combinations of analytes and biota in which body burdens in EFPC and floodplain samples were undetectable, were below the levels in reference site biota, or were less than five times the concentration in blank samples. Metals, PCBs, chlordane as a representative of pesticides, and PAHs were retained as COPCs for various biota. COCs were chosen after risk characterization for these analytes as described in the following sections.

Both historical and current studies of bioaccumulation show (1) higher body burdens of contaminants (mercury, PCBs, and various pesticides, PAHs, or metals) in common stonerollers, redbreast sunfish, crayfish, earthworms, and terrestrial insects at EFPC sites than at noncontaminated reference sites and (2) generally decreasing body burdens with increasing distance downstream from the Y-12 Plant. Current body burdens are generally lower than those from the 1980s, possibly as a result of prior remediation activities at the Y-12 Plant. Evidence of ecological recovery in the upper part of EFPC above and below Lake Reality has been documented by BMAP. Whole-body mercury concentrations found in redbreast sunfish during the BRA were 30 to 50% less than concentrations found in bluegill (*Lepomis macrochirus*) and redbreast sunfish taken from similarly located sites in studies conducted by ORNL in 1982 (Van Winkle et al. 1984) and by TVA in 1984 (TVA 1985). Other notable findings of the EFPC ecological BRA, which indicated a change in the general patterns documented by historical studies, were the high present body burdens of mercury in redbreast sunfish from a site located 6.4 km (3 miles) downstream from Lake Reality and increasing body burdens of PCBs in sunfish at this site and other sites downstream.

ES.3.2.3 Effects characterization

Data on the toxicity of inorganic and organic mercury compounds to fish demonstrate a positive relationship between dose and effect. Toxicity tests on a variety of aquatic and terrestrial organisms using EFPC surface water, soils, or sediments have shown deleterious effects, and in three studies the effects were greatest at the sites nearest the Y-12 Plant. The results of surveys of indicator organisms at EFPC also indicate effects that most likely occurred from exposure to contaminants released from the Y-12 Plant. The number of indicator fish species, benthic macroinvertebrate families, and insect adult individuals at EFPC generally increased with

Table ES.8. Summary table of trends for whole-body concentrations of contaminants in aquatic biota collected from EFPC and Hinds Creek, October 7–29, 1991

Taxon	Mercury	Other inorganics	PCBs		Pesticides	PAHs
			Aroclor 1260	Other		
Redbreast sunfish	• In samples from all six sites in EFPC and Hinds Creek. • Maximum at Site 3. • Decreasing body burdens downstream from Sites 3 to 6. • All samples in EFPC exceeded concentrations in sample from Hinds Creek.	• Uranium was below sample detection at all sites,	• In samples from all six sites in EFPC and Hinds Creek. • Maximum level at Site 3. • Decreasing body burdens. Downstream from Sites 3 to 6. • All samples in EFPC exceeded concentrations in sample from Hinds Creek.	• All other mixtures were below sample detection limits.	• Most were less than sample detection limit. • Chlordane, dieldrin, and heptachlor were in samples from all sites, including Hinds Creek. • Decreasing body burdens from Sites 1 to 2, then increasing to maximum at Sites 4 or 5. • Nearly all sites in EFPC exceeded Hinds Creek.	• All individual PAHs were below sample detection limits except for acenaphthene. • Acenaphthene body burden was greatest at Site 1, then nearly constant at remaining EFPC sites. • All samples in EFPC exceeded concentrations in samples from Hinds Creek.
Common stoneroller	• In all six samples from EFPC and Hinds Creek. • Maximum at Site 2. • Decreasing body burdens downstream from Sites 2 to 6. • All samples in EFPC except Site 6 exceeded Hinds Creek sample.	• Uranium in samples from all sites. • Maximum body burdens at Site 1. • Decreasing body burdens downstream from Sites 1 to 6. • Sites 1 to 4 exceeded Hinds Creek sample.	• Sufficient sample at Sites 1 to 5 and Hinds Creek. • Maximum at Site 1. • Decreasing body burdens downstream from Sites 1 to 4. • All samples in EFPC exceeded concentrations in samples from Hinds Creek.	• All the mixtures were below sample detection limit.	• Same sites as for PCBs. • Maximum at Site 1. • General trend of decreasing body burdens from Sites 1 to 4. • All samples in EFPC exceeded concentrations in samples from Hinds Creeks.	• Same sites as for PCBs. • Maximum at Site 1. • Same trend as for pesticides. • Nearly all sites in EFPC exceeded sample from Hinds Creek.

Table ES.8 (continued)

Taxon	Mercury	Other inorganics	PCBs		Pesticides	PAHs
			Aroclor 1260	Other		
Benthic macro-inverte-brates	• Sufficient sample only at 4 sites in EFPC and Hinds Creek. • Maximum at Site 2; other sites similar to each other. • All samples from EFPC exceeded sample from Hinds Creek.	• Same sites as for uranium and mercury. • Same trends as for mercury.	• Sufficient sample only at 2 sites in EFPC (Sites 1 and 2). • Maximum at Site 1 (6-fold greater than at Site 2).	• All other mixtures below sample detection limit.	• Same sites as for PCBs. • Nearly all were below sample detection limits.	• Same sites as for PCBs. • Most individual PAHs were similar to concentrations in samples from the two sites. • Fluoranthene was maximum at Site 1. • Benzo(a)pyrene was maximum at Site 2.
Crayfish	• Sufficient sample at 4 sites in EFPC and Hinds Creek. • Maximum at Site 1. • Decreasing body burdens downstream. • All samples from EFPC exceeded concentrations in samples from Hinds Creek.	• Same sites as for mercury. • Uranium was below sample detection limit at most sites. • Selenium body burdens were greatest in samples for Site 3, and all EFPC samples exceeded concentrations in samples from Hinds Creek.	• Same sites as for mercury. • Same trends as for mercury.	• All other mixtures below sample detection limit.	• Same sites as for mercury. • Nearly all were below sample detection limits.	• Sufficient sample only at Sites 1 to 3, and Hinds Creek. • Maximum at Site 3. • Most individual PAHs increased downstream from Sites 1 to 3. • Most PAHs at the 3 sites in EFPC exceeded concentrations in sample from Hinds Creek.

Table ES.9 Summary table of trends for whole-body contaminant concentrations in terrestrial biota collected from EFPC and reference site in late 1991

Taxon	Mercury	Other inorganics	PCBs		Pesticides	PAHs
			Aroclor 1260	Other		
White-footed mouse	• Levels below detection limit in 9 of 11 individuals. • Maximum value of 1.105 mg/kg at Site 2.	• Antimony, chromium, and selenium measured above detection limit in >50% of individuals.	• Above detection limits in all samples except reference. • Range from 0.051 mg/kg to 0.480 mg/kg, with highest at Site 1.	• All others below detection limit.	• Nearly all were below detection limits. • One value for DDT and one for heptachlor oxide above detection limits.	• All levels below detection limits or twice reference levels.
Short-tailed shrew	• Maximum of 7.9 mg/kg at Site 5.	• Uranium not detected. • Antimony, chromium, and selenium similar to mice.	• Maximum of 1.4 mg/kg at Site 5.	• Not detected.	• Nearly all were below detection limits.	• Not analyzed.
Woodland vole	• Less than detection limit.	• Chromium levels similar to mice. • Uranium not detected.	• Reported at 0.046 mg/kg.	• Aroclor 1016 at 0.073 mg/kg.	• All below detection limit.	• No unqualified levels above unqualified detection limits.

Table ES.9 (continued)

Taxon	Mercury	Other inorganics	PCBs		Pesticides	PAHs
			Aroclor 1260	Other		
Great blue heron	• Breast feathers at 5.3 mg/kg • Liver sample at 9.0 mg/kg.	• Chromium, selenium, and zinc above detection limits in feathers. • Selenium and zinc above detection limits in liver.	• Liver sample at 1.4 mg/kg.	• All others below detection limit.	• Several reported but most below the detection limit.	• No unqualified levels above detection limit.
Carolina wren	• Levels at 3.5 mg/kg in both samples.	• Antimony, selenium, and cadmium above levels in terrestrial insects.	• Average of 2.1 mg/kg is 10 times average in terrestrial insects.	• No others detected.	• Only DDE and heptachlor epoxide detected above detection limits.	• None above detection limit.
Flying insects	• Most samples below detection limit. • Maximum levels of 3.2 mg/kg at Site 3. • No correlation between measured concentrations in insects and soils.	• Uranium and cadmium not detected. • Antimony, chromium, zinc, arsenic and selenium noted above detection limits at 2 sites.	• Range of 0.02-0.35 mg/kg. • Maximum at Site 2 and decreased steadily with distance from Y-12 Plant.	• All levels below detection or reference site levels.	• DDE reported at Site 3, chlordanes at Site 4. • Others not identified above twice reference site levels.	• Few detected; highest value at Site 3.

Table ES.9 (continued)

Taxon	Mercury	Other inorganics	PCBs		Pesticides	PAHs
			Aroclor 1260	Other		
Earthworms	• Range from 5 to 33 mg/kg. • Maximum observed at Site 2, with a steady decrease downstream. • No good correlation between earthworm composites and soil levels.	• Arsenic, cadmium, selenium, uranium, zinc, and chromium levels above reference site.	• Not sufficient sample for analysis.	• Not sufficient sample for analysis.	• Not sufficient sample for analysis.	• Not sufficient sample for analysis.
Grass/ vegetables	• Geometric mean grass/browse concentration of 0.34 mg/kg, with maximum of 17 mg/kg. • Grasses near creek showed higher levels. • Levels in vegetables ranged from <0.03 to 3.2 mg/kg.	• Data not available.	• Not measured.	• Not measured.	• Not measured.	• Not measured.

increasing distance downstream from the Y-12 Plant. Compared with the Hinds Creek reference site, EFPC had fewer species of fish, fewer families of benthic macroinvertebrates, and lower mean numbers of individuals per sample of adult insects with terrestrial larval forms. The number of fish species classified as tolerant of degraded conditions decreased downstream in EFPC (Fig. ES.26). Taxonomic diversity (H') of fish, benthic macroinvertebrates, and adult insects increased downstream, except at Site 3, and was lowest at the three sites where surface water mercury concentrations were greatest (Fig. ES.27). Taxonomic diversity for fish, benthic macroinvertebrates, and adult insects with aquatic larval forms at EFPC sites was generally less than at the reference site. The richness of families from sensitive orders of arthropoda—Ephemeroptera, Plecoptera, and Trichoptera (EPT richness)—was lowest at the EFPC site nearest the Y-12 Plant and was lower at all EFPC sites than at the reference site (Fig. ES.28). In general, the results of the benthic macroinvertebrate sampling conducted to support the ERA parallel those of the fish sampling, suggesting that both communities (1) are dominated by large numbers of individuals from only a few of the total number of families present, (2) are dominated by tolerant organisms, (3) have less total species/taxa or EPT richness than the reference stream, and (4) have lower diversity indices than the reference stream. Taken together, these factors indicate that the benthic and fish communities in EFPC, especially in the upper part of the stream below Lake Reality, are experiencing environmental stress.

Although taxonomic richness (and presumably diversity) might be expected to increase in a typical stream as its drainage area or stream order increases (Fausch et al. 1984), the argument may be less applicable to EFPC because it does not possess the characteristics of a true headwater stream due to the augmented flow from the Y-12 Plant. Therefore, the increased taxonomic richness and diversity downstream from the Y-12 Plant is probably due more to reduction in toxicant concentrations downstream that to the increase in drainage area.

Studies of periphyton colonization and growth, populations of small mammals, earthworms, birds, and terrestrial vegetation showed less consistent patterns. A bird survey of EFPC in the fall of 1991, as well as other bird surveys, identified more than 30 species of migratory birds, which were likely ingesting contaminated worms and arthropods. White-footed mice were captured at all EFPC sites except Site 6. Short-tailed shrews, a woodland vole (*Microtus pinetorum*), and an eastern chipmunk (*Tamias striatus*) were captured at one or more of the sites furthest from the Y-12 Plant. A limited vegetation survey revealed no patterns associated with exposure to contaminants released from the Y-12 Plant. Earthworm contaminant body-burdens generally decrease as a function of distance from the Y-12 Plant. The threatened and endangered

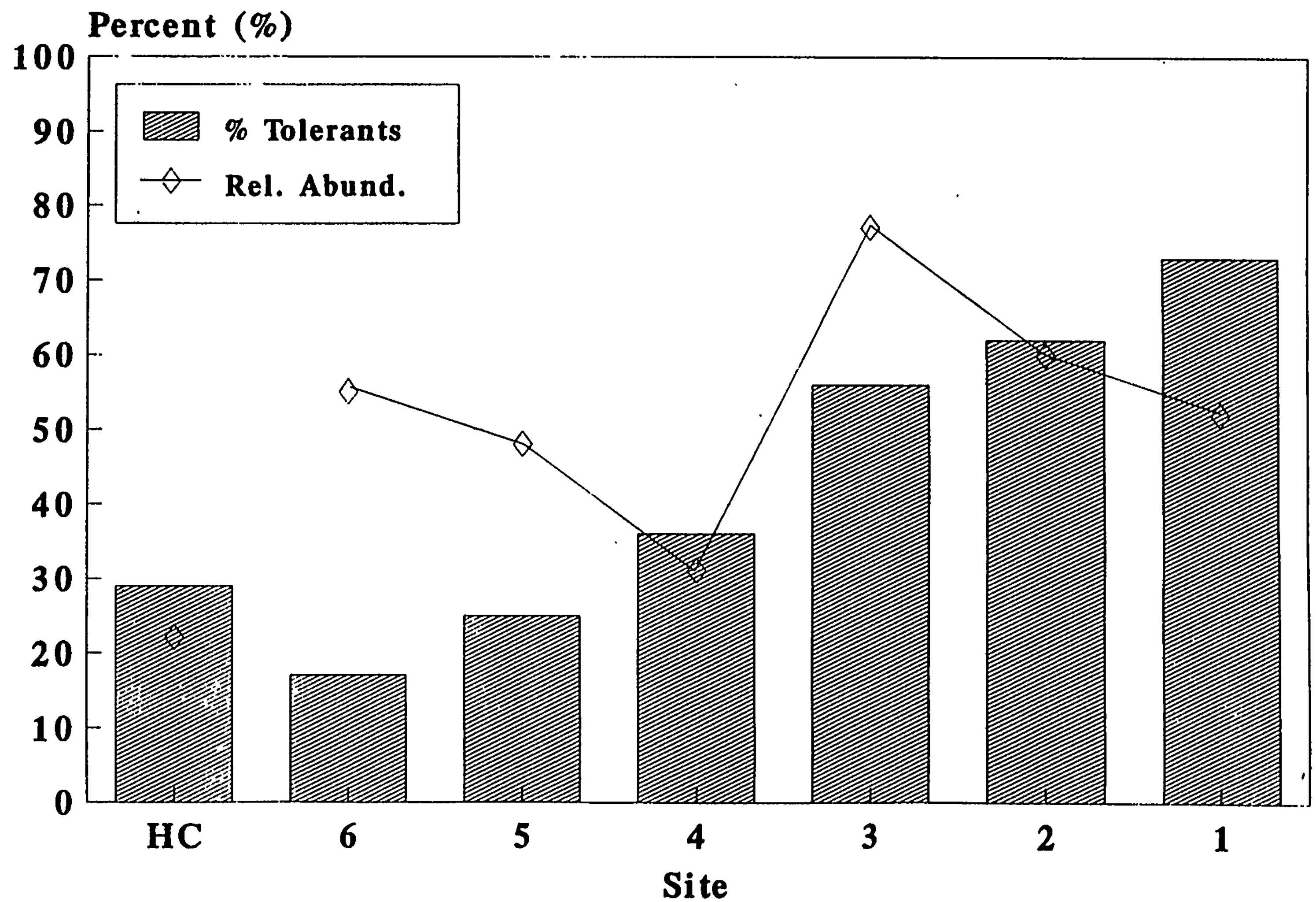

Fig. ES.26. Percentage of captured fish species from EFPC and Hinds Creek classified as tolerant of degraded water quality, October 7-12, 1991.

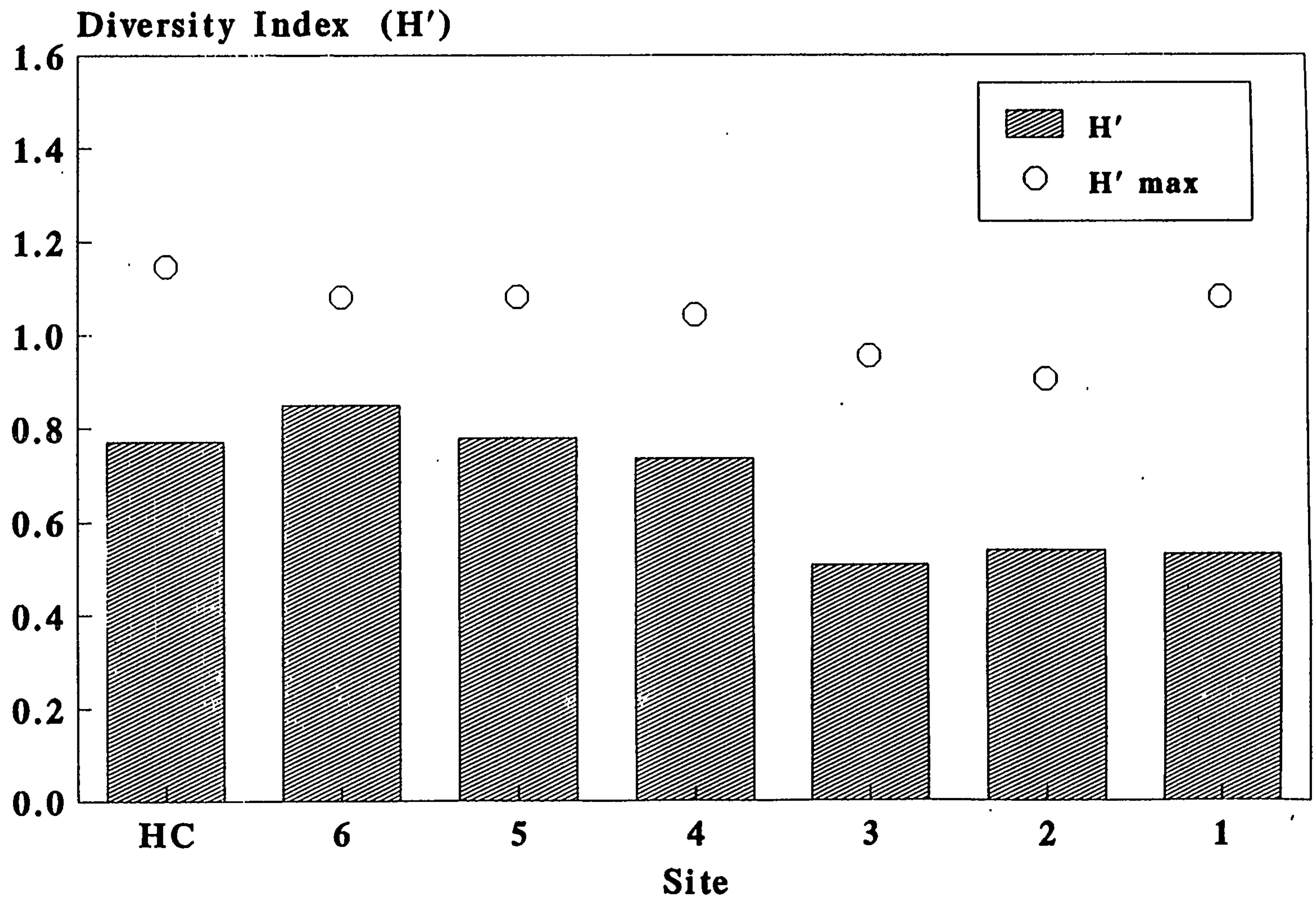

Fig. ES.27. Observed fish species diversity and maximum possible fish diversity at sites in EFPC and Hinds Creek, October 7-12, 1991.

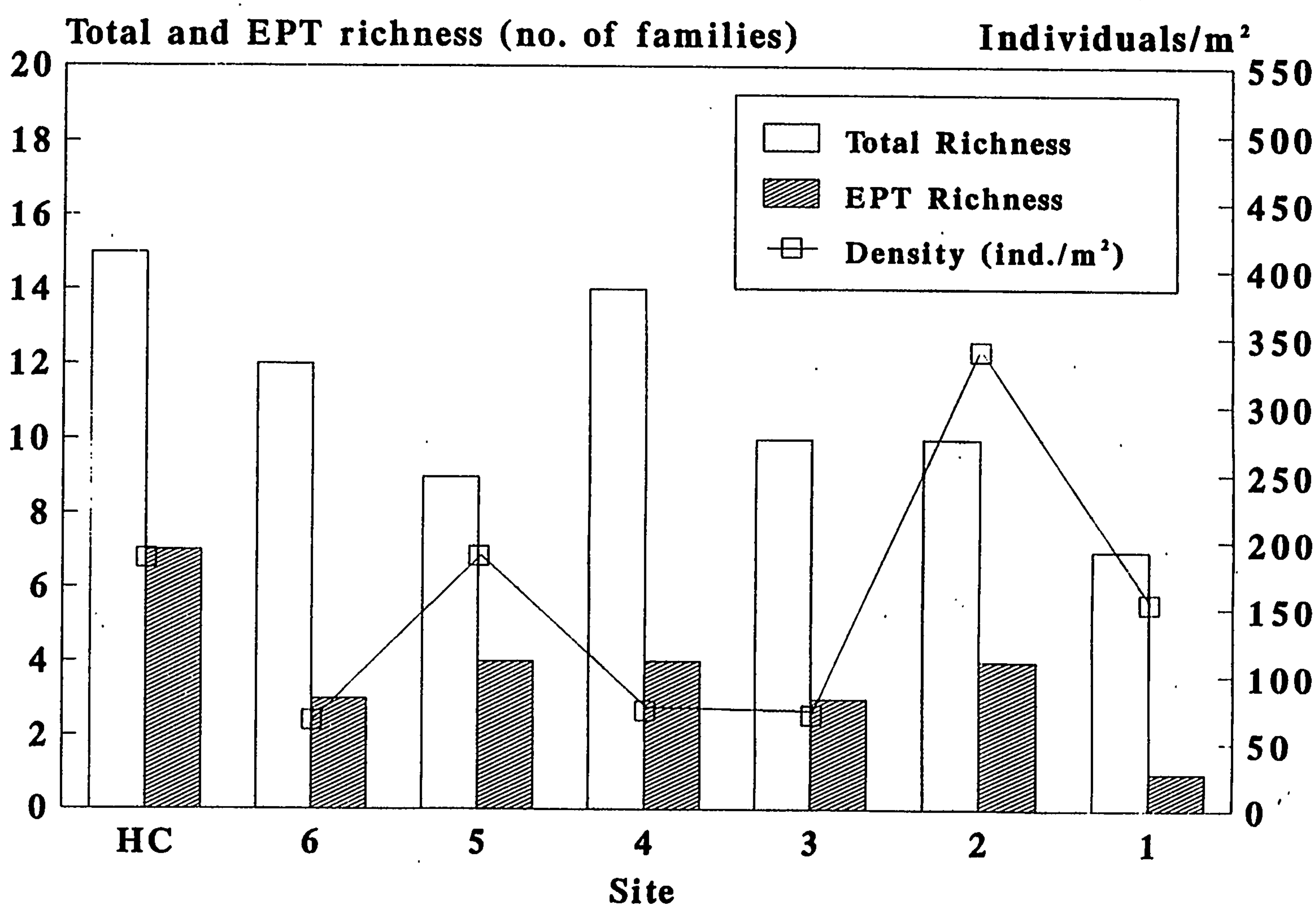

Fig. ES.28. Total family richness, EPT richness, and density (individuals per m^2) of benthic macroinvertebrates collected from EFPC and Hinds Creek, October 22-29, 1991.

species survey, both literature and field, revealed no species requiring protection of their populations or their support habitats.

ES.3.2.4 Risk characterization

Risk characterization aggregates the effects of exposure and stressor response on indicator organisms, summarizes risk according to the weight-of-evidence approach, and interprets the ecological significance of these findings. This ERA applied two interrelated approaches to ecological risk characterization for EFPC and its floodplain. The first was the application of the quotient method to various criteria for protection of ecological resources. In this method, measured concentrations are compared to threshold concentrations for protection of ecological resources (e.g., assessment endpoints). The ratio of the observed contaminant concentration to the protection thresholds indicates the severity of the impact or risk, with larger quotients indicating greater potential impacts or risks. The second approach was to apply weight-of-evidence arguments to evaluate the strength of the relationship between stressors and observed effects on indicator species and the implications for assessment endpoints.

Weight-of-evidence helps to identify causes of observed ecological responses, using arguments derived from human epidemiology. In this approach, a causal relationship between a stressor and a response is proposed. Then, a series of questions or criteria is applied to the proposition. Not all criteria must be satisfied to demonstrate that the proposition is true, but weight is added to a conclusion by each criterion that is satisfied in the proposition(s). Ultimately, professional judgment is used to establish the strength of the causal relationship. The weight-of-evidence approach is especially useful when (1) there are multiple lines of evidence to evaluate, (2) there are insufficient data for robust statistical analyses, (3) toxicity or other criteria are uncertain, or (4) exposure models are not sufficiently precise for statistical testing. As described by Suter and Loar (1992), the weight-of-evidence approach to ecological risk assessment is analogous to a civil court case in which physical evidence, witness accounts, and expert testimony are considered together to reach a verdict based on the preponderance of evidence. Rather than relying on a single line of evidence, the weight-of-evidence approach ideally incorporates three categories of biological investigation. First, toxicity testing of water, soil, and sediment to which biota are exposed provides direct measurement of effects on animal and plant indicator species. Second, biological surveys assess the current state of biota on the site (i.e., field-observed effects), and the results can be compared to a reference site or to the observations expected in the absence of contamination. Finally, body burdens of site-related contaminants can be measured as evidence of exposure and possible effects.

The ecological risks in this study are based on actual body burden data and surveys of organisms occupying the floodplain, while human health risks are not based on actual measurements of exposure in human bodies and are calculated by using standard exposure scenarios and exposure to a form of mercury that is a small portion of the mercury in the floodplain.

Quotient Methods Results. Risks to biota can be characterized by comparing exposure concentrations to specific threshold concentrations intended to be protective of the organism or its function in the ecosystem. Thus, criteria may be established to limit the concentrations of chemicals in surface water in order to protect aquatic biota (TDEC, Chap. 1200-4-3), or limits may be set on contaminant concentrations in tissues in order to protect organisms or their predators. Thresholds may also be established by modeling the transfer of contaminants from exposure media through the food chain to the various biotic receptors, thereby taking into account bioaccumulation of contaminants. In the quotient method, if the ratio of exposure concentration to threshold concentration is < 1, there is no problem or risk is considered insignificant, whereas if the quotient is sufficiently > 1, more study or computation is needed to define the exact degree of the risk that is inferred. Because of the uncertainty surrounding both sampling data and the threshold concentrations themselves, this approach requires careful interpretation of quotients near 1, but it provides a clear indication of high (≥ 10) or low (< 0.1) risks. The quotient method requires consideration of the uncertainty of estimating both the exposure concentration and the threshold values.

To address the assessment endpoints identified in Table ES.5 for the EFPC ERA, specific criteria and threshold concentrations were established for (1) ambient water quality; (2) aquatic biota and predator dietary uptake; (3) and body burdens in terrestrial mammals, birds, earthworms, and insects and predator dietary uptake. Threshold values for specific COPCs (in particular, mercury, other heavy metals, PCBs, chlordane, and PAHs) were established for each of these measures, and measured values in EFPC media and/or biota were compared to determine a quotient range. Tables ES.10 and ES.11 present the results of the quotient method for aquatic and terrestrial exposures, respectively. The tables identify those organisms at each EFPC site that fall within five quotient ranges. As noted in the quotient ranges, risks (≥ 10) are being predicted for both aquatic and terrestrial biota, primarily through mercury toxicity to predators through the food chain. The higher quotients tended toward the upstream sample locations along EFPC, with little ecological risk noted for the reference sites. Several additional findings are highlighted below.

Table ES.10. Classification of risk quotients for aquatic exposures by range and location[a]

Sample site	Quotient range[b]				
	Q>100	10≤Q<100	1≤Q<10	0.1≤Q<1	Q<0.1
1		WQC, Hg AI, pred. SR, PCB tox. SR, PCB pred.	CR, Hg tox. CR, PCB pred. RS, PCB tox. CR, PCB tox. RS, PCB pred.	WQC, Zn SR, Hg tox. RS, Hg tox.	
2		WQC, Hg SR, PCB tox. SR, PCB pred.	SR, Hg tox. CR, Hg tox. AI, pred. RS, PCB tox. RS, PCB pred.	WQC, Zn RS, Hg tox. CR, Hg tox. CR, PCB tox. CR, PCB pred.	
3		WQC, Hg	AI, pred. SR, PCB tox. RS, PCB tox. SR, PCB pred. RS, PCB pred.	WQC, Zn SR, Hg tox. RS, Hg tox. CR, Hg tox. CR, PCB tox. CR, PCB pred.	
4			AI, pred. SR, PCB tox. RS, PCB tox. SR, PCB pred. RS, PCB pred.	WQC, Zn SR, Hg tox. RS, Hg tox.	
5	HN, pred.	AI, pred.	HN, Hg tox. SR, PCB tox. RS, PCB tox. SR, PCB pred. RS, PCB pred.	WQC, Zn SR, Hg tox. RS, Hg tox. HN, PCB tox.	
6			SR, PCB tox. SR, PCB pred.	WQC, Zn CR, PCB tox. CR, PCB pred.	SR, Hg tox. RS, Hg tox. CR, Hg tox. CR, pred.

Table ES.10 (continued)

Sample site	Quotient range[b]				
	Q>100	10≤Q<100	1≤Q<10	0.1≤Q<1	Q<0.1
Reference				WQC, Zn SR, Hg pred. RS, Hg pred. CR, Hg pred. AI, Hg pred.	SR, Hg tox. RS, Hg tox. CR, Hg tox. SR, PCB tox. RS, PCB tox. CR, PCB tox. SR, PCB pred. RS, PCB pred. CR, PCB pred.

[a]Key:
WQC = Water quality criteria
SR = Common stoneroller
RS = Redbreast sunfish
CR = Crayfish
AI = Aquatic insect
tox. = toxicity to indicator organism
pred. = toxicity to predators
HN = Great blue heron
[b] Quotients based on concentrations below detection limits were not included.

Table ES.11. Classification of risk quotients for terrestrial exposures by range and location[a]

Sample site	Quotient range[b]				
	Q>100	10≤Q<100	1≤Q<10	0.1≤Q<1	Q<0.1
1	EW, pred.			TI, PCB pred. MS, PCB pred.	TI, PCB tox. MS, PCB tox.
2	EW, pred.	MS, pred. WR, pred.	WR, Hg tox. TI, pred.	MS, Hg tox. TI, PCB pred.	TI, PCB tox. MS, PCB tox. WR, PCB tox. MS, PCB pred. WR, PCB pred.
3	EW, pred.	TI, pred.		TI, PCB pred.	TI, PCB tox. MS, PCB tox. MS, PCB pred.
4	EW, pred.	SH, pred. WR, pred.	SH, Hg tox. WR, Hg tox.	WR, PCB tox. MS, PCB pred. SH, PCB pred. WP, PCB, pred.	TI, PCB tox. PCB tox. SH, PCB tox. PCB pred.
5	EW, pred. SH, pred.		SH, Hg tox.	SH, PCB pred. HN, PCB pred.	TI, PCB tox. MS, PCB tox. SH, PCB tox. TI, PCB pred. MS, PCB pred.
6		EW, pred.			TI, PCB tox. TI, PCB pred.
Reference			MS, Hg pred. EW, Hg pred.	MS, Hg tox.	TI, Hg tox. MS, HG tox. TI, PCB pred. MS, PCB pred.

[a] Key:
- EW = Earthworm (undepurated for conservative modeling results)
- TI = Terrestrial insect
- MS = White-footed mouse
- SH = Short-tailed shrew
- WR = Carolina wren
- tox. = toxicity to indicator organism
- pred. = toxicity to predators

[b] Quotients based on concentrations below detection limits were not included.

- **Toxicological effects.** Comparison of mercury body burden concentrations with concentrations that have been proposed as protective against toxicological effects in the indicator organisms [0.5 mg/kg (Eisler 1987)] showed that 2 of 7 crayfish samples and 1 of 10 common stoneroller composite samples had mercury concentrations exceeding toxicological limits (5 mg/kg body weight). Body burdens of mercury in short-tailed shrews were considerably above the toxicological limit (1.1 mg/kg body weight), and the feathers and liver of a great blue heron also exceeded toxicological limits (1.1 mg/kg).

- **Protection of predators.** Comparison of body burdens of contaminants in aquatic biota with concentrations expected to protect their predators from toxicological effects showed that mercury concentrations in fish exceeded the threshold concentration for mercury by ten-fold or more at sites 1, 2, and 3. Concentrations in crayfish exceeded the threshold concentration for mercury by at least ten-fold at the two sites closest to the Y-12 Plant, and mercury concentrations in aquatic insects exceeded the threshold concentration by at least ten-fold at two sites. Application of the same comparison to low-level terrestrial predators (small mammals and song birds) preying on contaminated organisms showed that undepurated earthworms at every site exceeded threshold concentrations for dietary mercury. Assuming all the mercury in the undepurated earthworms is bioavailable, exposure was calculated to be high, even if earthworms were only a small fraction of a predator's diet. Bioaccumulation factors for mercury in earthworms may be on the order of 0.1, so that the contribution of earthworm tissue to the predator's dietary exposure is probably much lower than indicated by the undepurated body burden. Insectivores feeding exclusively or predominantly in contaminated areas of the floodplain would be at risk from ingestion of mercury. Excessive levels of mercury in short-tailed shrews and Carolina wrens likely result from their consumption of earthworms and insects, respectively, and, in turn, contribute to the risk of those animals that prey on them. Other metals, pesticides, and PAHs did not appear to pose a risk to aquatic and low-level terrestrial predators. PCBs in common stonerollers exceed threshold concentrations at sites 1 and 2 but did not appear to pose a risk in other biota or in stonerollers at other sites.

Top predators, represented by hawks, owls, and foxes, were assumed to feed on a mix of the biota sampled in three ecological risk zones, comprising risk assessment segments 1 through 4, 5 through 8, and 9 (Fig. ES.8), respectively, as well as the reference areas at Hinds Creek and Mill Branch. The high-end exposure was calculated with the assumption that the top predators eat no uncontaminated prey. In this case, the composite prey body burdens of mercury exceeded dietary threshold concentrations for hawks and owls by at least 25-fold in all three zones. The mercury threshold for foxes was not exceeded in any zone, nor were thresholds for other metals, PCBs, pesticides, or PAHs. When the estimated exposures were adjusted to allow for dietary intake of uncontaminated prey from outside the contaminated areas, dietary thresholds were not exceeded for hawks or foxes and were exceeded for mercury by less than two-fold in the modeled diet of owls.

Weight-of-evidence results. The weight-of-evidence analysis focused on risk to both aquatic and terrestrial ecological receptors. Three propositions were advanced for aquatic biota; these propositions were conclusions based on the results of the ERA field sampling as well as on historical studies of EFPC. The three propositions each began with the statement, "Continual releases of water-borne contaminants (including dissolved and particle-bound) such as mercury, uranium, other inorganics, pesticides, PAHs, and Aroclor 1260 from the Y-12 Plant," and are as follows:

> Proposition 1 — Continual releases of water-borne contaminants . . . from the Y-12 Plant are the largest source of the elevated whole-body burdens of these contaminants in fish, benthic macroinvertebrates, and crayfish in EFPC, which result in risk from toxicological effects to indicator organisms and risk to piscivorous predators feeding on the organisms.
>
> Proposition 2 — Continual releases of water-borne contaminants . . . from the Y-12 Plant impact fish community structure in EFPC, resulting in communities dominated by species tolerant of degraded water quality conditions.
>
> Proposition 3 — Continual releases of water-borne contaminants . . . from the Y-12 Plant result in reduced taxonomic richness and diversity of the fish and benthic macroinvertebrate communities in EFPC compared to the same measurements in communities at the reference site.

The aquatic propositions were evaluated against five criteria (temporal association, spatial association, stressor-response, strength of association, and plausibility) and qualitatively ranked (as strong, moderate, or weak) based on the level of available evidence. Major observations from the ERA field sampling and historical studies indicate that numerous COPC body burdens in the aquatic indicator organisms (common stonerollers, redbreast sunfish, crayfish, and benthic macroinvertebrates) as well as several measures of community structure (fish and benthic macroinvertebrates, taxonomic richness and diversity, and percentage of fish species classified as tolerants) are greatest at locations closest to the Y-12 Plant, then decrease downstream in EFPC. In addition, COPC body burdens and community impacts in biota from all sites in EFPC usually were greater than equivalent impacts at the Hinds Creek reference site.

The data for mercury and PCBs indicate a clear temporal association between the release of these two contaminants from the Y-12 Plant and their subsequent bioaccumulation in aquatic biota downstream in EFPC. Several variables (such as the percentage of captured fish species that are classified as tolerant of degraded water quality conditions, fish and benthic macroinvertebrate taxa richness, and species diversity) have consistently indicated that aquatic biota in EFPC are adversely impacted in comparison to biota in the Hinds Creek reference stream. However, BMAP researchers have concluded that recent increases in taxa richness of fish and benthic macroinvertebrates, as well as increased survival and growth of clams in EFPC below Lake Reality, indicate ecological recovery that is temporally related to improved control of toxicant releases from the Y-12 Plant (Appendix R, pages R-36 through R-65).

Both current and historical evidence suggest that spatial associations are strong for all three propositions. Body burdens of many COPCs were greatest in biota collected closest to the Y-12 Plant and decreased downstream. Also, the COPC body burdens in biota from most sites in EFPC were greater than the body burdens in biota from the reference site. Similar trends were observed for the percentage of tolerant fish species (Proposition 2). Fish and benthic macroinvertebrate taxonomic richness and diversity (Proposition 3) generally increased downstream from the Y-12 Plant, indicating that the most severe impacts occurred closest to the plant.

Stressor-response associations were evaluated by determining linear correlation coefficients between estimated COPC exposure concentrations (the stressor) and the magnitude of some response variable (e.g., percentage of fish classified as tolerants). In the absence of COPC concentration data in surface water, COPC body burden concentrations were used as an indicator of the stressor exposure level.

Mercury in surface water was significantly correlated with mercury body burdens in crayfish. Of the COPCs that were below detection limits in surface water, ten were present in at least one of the aquatic indicator organisms at body burden concentrations that were maximum in samples collected closest to the Y-12 Plant, then decreased downstream. Mercury concentrations in surface water were correlated with the percentage of fish classified as tolerants, but zinc concentrations in surface water were not correlated (Proposition 2). Five contaminant body burdens in common stonerollers were correlated with the percentage of fish classified as tolerants. Evidence of stressor-response associations between COPC concentrations and taxonomic richness or diversity (Proposition 3) were practically absent. Thus, the data suggest a strong stressor-response association for Proposition 1, a moderate association for Proposition 2, and a weak association for Proposition 3.

Strength of association for all three propositions is strong. For example, body burdens of most contaminants decreased downstream from the Y-12 Plant, whereas urban runoff and point source contaminants increased downstream. Habitat-altering activities, such as dredging or impounding (which could have potential adverse impacts to fish and benthic macroinvertebrate communities), have not been conducted extensively in EFPC. Concentrations of residual chlorine, which is a potential chemical toxicant, did not exceed the EPA ambient water quality criteria (AWQC) for protection of aquatic life (11 μg/L) during BMAP 7-d media toxicity tests. Loar (1992) stated that although episodic increases of chlorine concentration probably affect benthos at EFK 24.4 (above former New Hope Pond), the chlorine concentrations cannot account for the low abundance and diversity at EFK 23.4.

Likewise, plausibility for all three propositions is strong. The COPCs from this study are known to bioaccumulate in most aquatic organisms. Although most COPC concentrations in surface water were below detection limits, the large number of COPC body burdens displaying longitudinal decreases in concentration downstream from the Y-12 Plant suggests that the Y-12 Plant is the source of the COPCs in the biota (Proposition 1). Propositions 2 and 3 are plausible because the surface water mercury concentrations (0.54 to 0.32 μg/L) at the three sites closest to the Y-12 Plant exceed the concentration known to cause toxic effects in fish (<0.1 μg/L). This alone could account for the observed impacts to the fish and benthic macroinvertebrate community structure and diversity.

The conclusions from the weight-of-evidence analysis have implications for the assessment endpoints associated with Goals 4 (a fish community indicative of undegraded conditions) and 5 (no adverse effects from contaminants to aquatic organisms and/or predators that feed on them) (see Table ES.5). For example, aqueous mercury concentrations in EFPC exceeding levels known to produce toxicological impacts to sensitive (e.g., <0.1 μg/L in rainbow trout) as well as tolerant species (e.g., 0.23 μg/L in fathead minnows) have been observed. This alone could affect community structure (Goal 4 and its assessment endpoint), as demonstrated by the increased proportion of tolerant fish species (Proposition 2) and the impacts to taxonomic richness and diversity (Proposition 3). Elevated aqueous mercury concentrations exceeding AWQC also place fish and benthic macroinvertebrate communities at risk, which links to Goal 5 and assessment endpoint 5a. Elevated body burdens of mercury and other contaminants continue to place aquatic organisms and their predators at risk (Goal 5, assessment endpoints 5b and 5c). The aquatic weight-of-evidence analysis indicates that Goals 4 and 5 are not being met, most likely due to ongoing releases of contaminants from the Y-12 Plant.

The weight-of-evidence analysis for the terrestrial biota makes two propositions concerning EFPC soil contaminants. Common to both propositions is the premise that EFPC soil contaminants were released from the Y-12 Plant and were transported by and deposited from EFPC surface water. The propositions are as follows:

(1) EFPC soil contaminants have resulted in elevated body burdens of these contaminants in terrestrial organisms residing on the floodplain, as indicated by field-observed measurements of earthworms, small mammals, and birds.

(2) EFPC soil contaminants have resulted in reduced abundance of terrestrial organisms residing on the floodplain, as indicated by field-observed measurements of terrestrial populations.

The terrestrial weight-of-evidence analysis evaluated four criteria (spatial association, stressor-response, strength of association, and plausibility). The propositions explicitly address a subset of the EFPC terrestrial community—the animal indicator species associated with the assessment and measurement endpoints. These species are generally ubiquitous and, for one or more of their life stages, relatively sedentary inhabitants of the floodplain. The 10 families of insects considered in detail in the following analysis are inhabitants of soil, soil surface, or herbaceous vegetation, or are predators of other such inhabitants (Borror and DeLong 1964).

The spatial association for Proposition 1 is supported by the fact that concentrations of mercury and five other metals in undepurated earthworms; cadmium, zinc, and Aroclor 1260 in white-footed mice; and 6 metals, Aroclor 1260, and some pesticides in insects from most sites in EFPC exceeded those in biota from the reference site. Also, body burdens of mercury in undepurated earthworms generally decreased with increasing distance from the Y-12 Plant. This also supports the stressor-response relationship for Proposition 1 because maximum mercury concentrations in surface soils nearest the creek bank of EFPC decreased with increasing distance from the Y-12 Plant, as did soil mercury concentrations at the biotic sampling sites (with the exception of Site 1, which has only a narrow floodplain). The strength of association and plausibility of Proposition 1 are high, given that the only known source of mercury and other contaminants to terrestrial biota is the EFPC floodplain soils.

The spatial association and stressor-response relationship for Proposition 2 are supported by the inverse relationship between soil mercury concentrations and abundances of ten families of insects with terrestrial juveniles that represent a majority of all insects captured. There are no such similar trends in abundance for small mammals, birds, and earthworms. Published dose-response data for terrestrial annelids suggest that mercury concentrations in EFPC soils may be high enough to adversely affect soil-dwelling insects. The strength of association and plausibility of Proposition 2 are moderate. Insect groups showing a spatial association with mercury concentrations in EFPC soils comprise between 70 and 84% of all terrestrial insects captured at the six biotic sampling sites. The increase in abundance with increasing distance from the Y-12 Plant exhibited by the three dominant groups of insects is strong evidence that one or more physical or chemical stressors associated with EFPC diminish with increasing distance downstream. The most plausible cause of this pattern is the decrease in soil contaminant concentration, although other stressors or subtle habitat differences may also influence the observed pattern of insect abundance.

It is concluded that increased body burdens of mercury and other contaminants in earthworms, mice, shrews, and wrens result from EFPC soil contaminants that originated at the Y-12 Plant and were transported by and deposited from EFPC surface water onto the floodplain. It is also concluded that the decreased abundances of 10 families of insects with terrestrial juveniles at EFPC biotic sample sites nearest the Y-12 Plant (especially Sites 1, 2, and 3) result from EFPC soil contaminants. While this suggests that insect abundances may have been reduced by contaminants in EFPC floodplain soils, there is insufficient evidence to conclude that the terrestrial insect community at any EFPC site is indicative of degraded conditions, as defined in assessment endpoint 6a, because of habitat differences between the EFPC and Hinds Creek sampling sites. Population densities of other terrestrial indicator organisms were typically higher than at the reference site.

These conclusions have implications for the assessment endpoints. The propositions link directly to Goal 7—the protection of terrestrial animals and their predators from the effects of contaminants. Elevated body burdens of EFPC contaminants in earthworms and their predators put still other unsampled and unanalyzed terrestrial predators on the EFPC floodplain at risk from exposure to these contaminants. The propositions link indirectly to Goal 2 because terrestrial organisms represent an essential resource for migratory birds passing through or residing seasonally on the floodplain. Reductions in insect abundances may decrease the carrying capacity of EFPC for numerous species of insectivorous birds that raise their young on the floodplain in the summer. Combined with elevated body burdens of contaminants in insects, this represents an even more potentially serious risk to bird populations. Thus, Goals 2 and 7, the protection of migratory birds and the protection of terrestrial animals and their predators, are probably not being met in some portions of the EFPC floodplain as a result of EFPC soil contaminants that originated at the Y-12 Plant and were transported by and deposited from EFPC surface water onto the floodplain.

ES.3.2.5 Spatial distribution of ecological risk

The floodplain was organized into nine risk assessment segments (Fig. ES.29), based on geography, uniformity of land use, and similarity of contaminant levels. A more descriptive explanation of the criteria for segment selection is found in Sect. 5 of the RI. Segments 1, 2, 3, and 4 are located in the upper reaches or part of the creek, below Lake Reality, whereas Segments 5, 6, 7, and 8 are located further downstream along the east-west axis of the stream. The longest segment (Segment 9) covers approximately the last 25% of the EFPC floodplain, and its western edge is located at the confluence with Poplar Creek. The nine segments used for this ERA are the same as those used for the human health risk assessment.

Ecological risk differs from segment to segment along the ~23-km (14.5-mile) course of EFPC. Risk varies according to noticeable trends in exposure to contaminants, as measured by comparing contaminant body burdens relative to protective benchmarks (quotients) and weight-of-evidence discussions on spatial associations. The decrease in most contaminant body burdens, ecological community effects, and risk quotients with distance downstream from the Y-12 Plant indicates that ecological risk is highest in Segments 1, 2, 3, and 4, which are the segments closest to the source of contamination. Several contaminated wetlands with resident invertebrates, amphibians, and other animals also occur in these segments. Ecological risk is lowest in Segment 9, which is the segment farthest downstream from Y-12; contaminant body burdens and other assessment endpoint measures are also lowest in Segment 9. Ecological risk is intermediate in Segments 5, 6, 7, and 8, which are located in the midstream portion of EFPC. Table ES.12 summarizes these and related trends.

Along this overall gradient of ecological risk and within each segment, two types of ecological resources are at risk: aquatic and terrestrial. Aquatic resources—fish, benthic macroinvertebrates, and primary producers—are at highest risk because they live in the water or in sediments and are exposed continuously via body contact. Risks to aquatic biota are greatest immediately downstream from the Y-12 Plant (EFK 20-23), where the highest aqueous mercury levels were observed. Every ERA contaminant sampling location in EFPC provided contaminated prey to fish-eating predators. Exposures to aquatic and piscivorous biota generally decrease downstream. Aquatic ecological resources are subjected to a greater risk, segment by segment, than are the terrestrial resources in the corresponding segment.

Although biomagnification has in some cases resulted in body burdens well above the benchmarks used for risk estimation, measurements of body burdens show that terrestrial resources—birds, small mammals, earthworms, arthropods, and vegetation—generally exhibit less

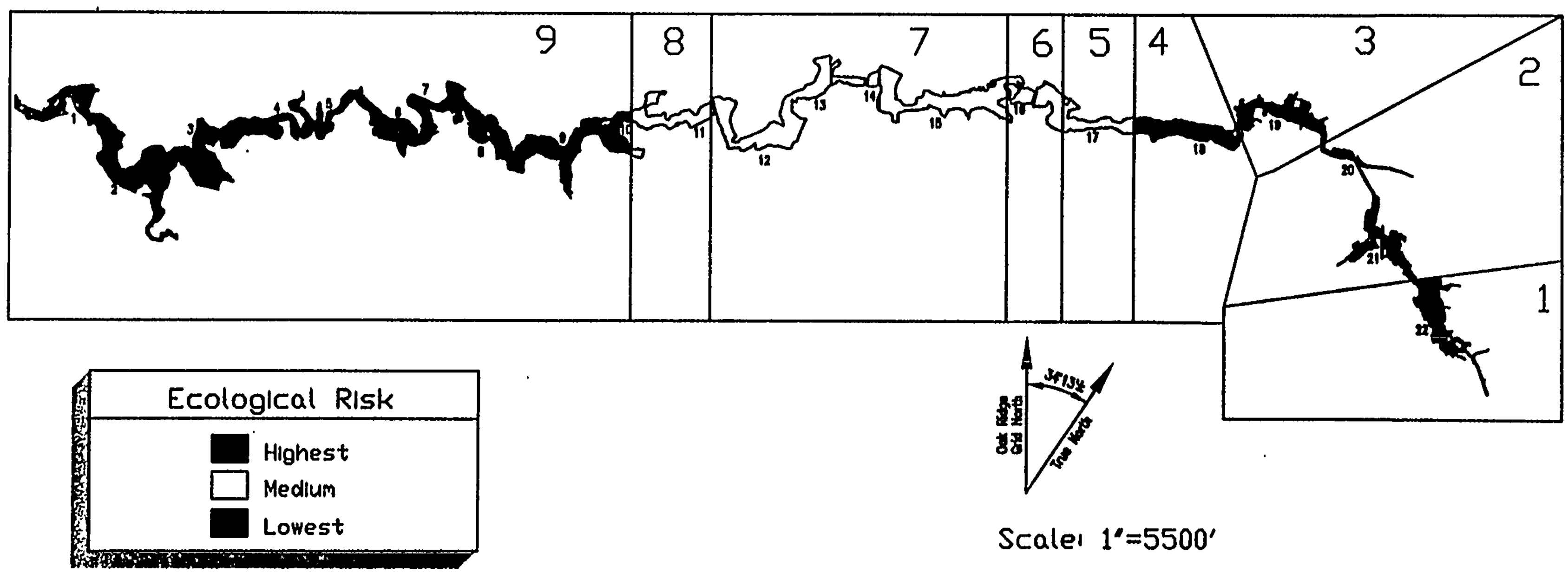

Fig. ES.29. Ecological risk for aquatic and terrestrial resources under current conditions. (Small numbers correspond to creek km.)

Table ES.12. Patterns of measurement endpoints for the three ecological risk assessment segments

Media and measurement endpoints	Location in 23-km (14.5-mi) long floodplain		
	Upper reaches (Segments 1, 2, 3, and 4)	Middle reaches (Segments 5, 6, 7, and 8)	Lower reaches (Segment 9)
Abiotic media			
Water contaminants	Highest	Intermediate	Lowest
Soil contaminants	Highest	Intermediate	Lowest
Aquatic organisms			
Fish			
Tolerant species	Highest	Intermediate	Similar to reference
Species evenness	Lowest	Similar to highest	Highest
Contaminant body burdens	Highest	Intermediate	Lowest
Benthic macroinvertebrates			
Tolerant species	Highest	Intermediate	Similar to middle reaches
Species evenness	Lowest	Similar to highest	Highest
EPT richness	Lowest	Intermediate	Similar to middle reaches
Terrestrial organisms			
Arthropod mean abundance	Lowest	Intermediate	Highest
Contaminant body burdens for earthworms and mice	Highest	Intermediate	Lowest

risk and less definitive trends than the aquatic resources for any particular segment within the floodplain. Exposures to terrestrial animals are primarily via contaminated animal food, in which contaminant levels are related to soil contaminant concentrations. Initial work shows that terrestrial areas of highest mercury concentrations are sometimes found in the bottomland hardwood forests, where flooding is most likely to have occurred. As explained in the risk quotient and terrestrial weight-of-evidence sections, some available terrestrial measurements show trends, particularly decreasing contaminant body burdens as distance from the Y-12 Plant increases. Thus, both the aquatic and terrestrial organisms in the EFPC environment are at differing risks as a function of distance from the Y-12 Plant. In turn, these ecological risks are in three large patterns: (1) highest in Segments 1, 2, 3, and 4 (upper reach); (2) intermediate in Segments 5, 6, 7, and 8 (middle reach); and (3) lowest in Segment 9 (lower reach).

Selection of COCs. On the basis of results described in the preceding risk characterization subsections, mercury and PCBs are retained as COCs for both aquatic and terrestrial biota. Other COPCs did not appear to provide exposures consistently above threshold concentrations used in the risk characterization.

ES.3.2.6 Future exposures and risks

Many future exposure scenarios are possible. If there is no remediation at either the Y-12 Plant or the EFPC floodplain, exposures of the biota are not likely to change significantly. Bioaccumulation and biomagnification may cause an increase in contaminant load in long-lived terrestrial biota. However, because most of the soil contaminants have been in place for 30 years or more, most of the food taxa have probably reached steady-state body burdens. Cessation of releases from routine Y-12 Plant operations would likely reduce chronic exposures in EFPC, but releases into EFPC by stormwater runoff from the Y-12 Plant into EFPC would likely continue. Changes in Y-12 Plant operations to reduce the volume of water, but not the mass of contaminants, flowing into EFPC could increase exposure concentrations to aquatic biota. Closure of the Y-12 Plant would alter the base flow of EFPC, causing disruption of many biotic communities, especially in the upper reaches of the creek. Because ongoing releases of contaminants from the Y-12 Plant into EFPC appear to dominate the effects on aquatic biota in EFPC, changes in the baseline contaminant body burdens that would result if the EFPC floodplain and sediments were the only source of contaminants to surface water are not clear. Studies are in progress to assess sediment toxicity and relationships between sediments and transfer of contaminants to aquatic biota.

The future (i.e., assuming no change from current conditions) would result in the continued exposure of (1) aquatic biota that directly contact and ingest EFPC surface water, sediment, and food; (2) aquatic predators that prey on other contaminated aquatic organisms or terrestrial insects; (3) terrestrial animals that dwell in or consume contaminated soil; and (4) terrestrial predators that prey on contaminated aquatic or terrestrial animals in the EFPC floodplain. The continued exposures of aquatic and terrestrial biota and their habitats to contaminants would result in continued elevated body burdens of contaminants in these biota and risk to their predators, along with impacts to community structure and taxa diversity.

Wetlands in contaminated areas of the floodplain would continue to receive contaminants transported by storm flow. Contaminated soils could act as a source of contamination to wetlands in the watershed. Contaminated soils could be eroded and transported as suspended load in the high flow of flood events. As flow velocity decreases and flood waters recede, contaminants transported as suspended solids drop out of suspension and are redeposited in wetlands in another part of the floodplain. Because wetlands in the EFPC floodplain have formed in low-lying areas of the floodplain subject to deposition, the wetlands could receive future contaminants. In this manner, contaminants could migrate, and relatively uncontaminated soils in the floodplain downstream from the source area could become contaminated. In the future, contaminated soils in wetlands would remain a potential source of contamination to numerous other receptors, including soil, sediment, surface water, groundwater, plants, animals, and humans.

The floodplain contains trees, some of which have cavities and other hiding/brood places for bats. These trees are likely to remain, continuing to provide potential habitat to threatened and endangered bat species. However, the endangered Indiana bat (*Myotis sodalis*) has major population centers in Missouri and Kentucky and is not likely to reach eastern Tennessee. The endangered gray bat (*Myotis grisescens*) is also concentrated in cave regions; the species is mostly found in Arkansas, Missouri, Kentucky, Tennessee, and Alabama and forages primarily along rivers or lake shores. This bat is not likely to expand its range to the small stream area of EFPC. The Tennessee dace (*Phoxinus tennesseensis*), a state-listed fish found in several tributaries to EFPC, may move into EFPC.

ES.3.2.7 Comparison of ERA results with assessment endpoints

As documented in the Problem Formulation phase of this ERA (Table ES.5), 12 assessment endpoints were identified that would help to determine whether existing site conditions provided attainment of the goals set for the EFPC watershed. Following the conclusion of the Exposure Characterization, Effect Characterization, and Risk Characterization phases, and within the limits of the uncertainties associated with this type of study, the risk assessment can be compared to these baseline assessment endpoints to get a clearer picture of the overall ERA results. Table ES.13 provides a listing of the defined endpoints along with the respective ERA results from direct surveys or risk characterization analyses (quotient or weight-of-evidence). A few key results of this comparison and conclusions from the ecological risk follow:

- a few of the assessment endpoints (assessment endpoint 1a and possibly 1b, 1c, and 2a in Table ES.13 were achieved with existing EFPC contaminant conditions;
- one assessment endpoint (6a) is achieved for some receptors at some places and not achieved for one receptor at all places; and
- measurements or risk characterization method results indicate that the rest of the assessment endpoints cannot be met in parts of the EFPC floodplain under existing conditions, i.e., many body burdens exceed the protective concentrations.

These and the following conclusions summarize the baseline ecological risk assessment for EFPC:

- There is ongoing risk to ecological resources, particularly aquatic organisms in the upper part of the creek, from exposure to contaminants in environmental and biological media of EFPC. The results of the ERA do not indicate a need for immediate short-term action to mitigate exposures or risks to ecological health.
- Direct contact with and ingestion of surface water, sediment, and sediment pore water are primary exposure pathways for aquatic biota. The food chain is also a primary exposure pathway for aquatic fauna. Releases from the Y-12 Plant are the primary source of water-borne contaminants. Additional contributions, albeit much smaller, to ecological risk come from the municipal sewage treatment plant and other point and non-point sources along the creek. Experiments at ORNL on fish uptake in tanks containing mercury-laden waters from Lake Reality, both with and without a contaminated sediment substrate, establish the minor role of sediments as a source of exposure to aquatic organisms. Studies are in progress to assess the toxicity of sediments from EFPC on aquatic organisms.
- The food chain is the most important exposure pathway for terrestrial fauna. Exposures to terrestrial biota also come from contaminant deposits in the EFPC floodplain soils, via direct contact and inhalation. These exposures result in ecological risk quotients in excess of 10 and 100 to predators of earthworms and insects. Predators of small mammals and birds are

Table ES.13. Comparison of ERA results with assessment endpoints

Assessment endpoint	ERA result
1a. No harm to any threatened and endangered species and their critical habitat of the EFPC floodplain	1a. Literature and field surveys did not reveal threatened and endangered species living in EFPC floodplain. Habitat that could support an expansion of the range of a threatened and endangered species (e.g., Indiana and Gray bats) was found. However, a range expansion of such species is not likely.
1b. Maintenance of plant community composition and/or structure required for rare plant and animal and support species	1b. Literature and field surveys did not find that potential habitat—plant community—for rare animal or support species was harmed by EFPC contaminants. Wetlands may be an exception depending on the remediation goal option.
1c. No exposure to threatened and endangered species through biomagnifiable contaminants through the food chain	1c. Literature and field surveys and consultation with responsible agencies did not reveal threatened and endangered species living in the EFPC floodplain.
2a. No killing or harming of migratory birds as a result of exposure to site-specific stressors	2a. Field survey evidence provides names of more than 30 migrant bird species which are likely ingesting contaminated worms and arthropods and, therefore, likely being affected by EFPC contaminants.
3a. The presence and structure/function of wetlands in relation to contaminants	3a. Seventeen wetlands exist in the floodplain, some with mercury contamination, but each appears to exhibit undegraded structure and functions. (There is an ongoing contaminant sampling to establish this).
4a. Fish communities in which the proportion of species tolerant of degraded water quality is <30%	4a. Continual releases of water-borne contaminants impact fish community structure, resulting in communities dominated by species tolerant of degraded water quality conditions at the 4 sites closest to the Y-12 Plant.
5a. Ratio of contaminant concentration in surface water to water quality criteria for protection of aquatic life ≤1. These criteria are 0.012 μg Hg/L and 0.001 μg PCB/L.	5a. The quotient method indicated significant exceedances by factors up to 45 from mercury concentrations above water quality criteria of EFPC below Lake Reality.
5b. Aquatic indicator organisms contaminated body burden ratio to toxicological effects levels ≤1. These levels are 5 mg Hg/kg and 0.4 mg PCB/kg.	5b. Contaminant body burden measurements and quotients of 1 or less for mercury and up to 20 for PCBs were determined for common stonerollers, redbreast sunfish, and crayfish.
5c. Fish contaminant body burden ratio to protect piscivorous biota levels ≤1. These levels are 0.1 mg Hg/kg and 0.5 mg PCB/kg.	5c. The quotient method identified numerous exceedances by factors of 10 to >100 for mercury and up to 16 for PCBs for fish contaminant body burdens in a predator pathway.
6a. Terrestrial animals with diversity, abundance, and distributions indicative of undegraded conditions resulting in ≥20 or more percent decrease compared to the reference.	6a. Terrestrial insect abundance was more than 20% lower at all EFPC sites than at the reference site. Other findings suggest that no 20% decreases occur for other indicator organisms.
7a. Ratio of contaminant body burdens in terrestrial indicator species to toxicological effects levels ≤1. These levels are 1.1 mg Hg/kg and 16 mg PCB/kg.	7a. Body burdens of Great blue heron, Carolina wrens, and short-tailed shrews were found to exhibit quotient ranges between about 2 and 8 for mercury in the ERA sampling.
7b. Ratio of contaminant body burdens in terrestrial indicator species to levels protective of terrestrial predators ≤1. These levels are 0.05 mg Hg/kg and 3.0 mg PCB/kg.	7b. Contaminant body burden quotients in excess of 100 were determined for Great blue herons, earthworms, and short-tailed shrews for predator pathways. Quotients for mercury were as high as 19 for white-footed mice and 70 for Carolina wren predators.

at risk according to modeled pathways of contaminant uptake if those predators obtain the majority of their food from the EFPC floodplain.

- Methylmercury concentrations were very low in EFPC soils and sediments; however, methylmercury was assumed to be the predominant mercury species in aquatic biota, including flying insects, based on data from the BMAP and other evidence. Consumption of contaminated aquatic biota provides risk to terrestrial and aquatic piscivores.

- Evidence suggests that some ecological recovery of the aquatic ecological community has been occurring in the upper reaches of the creek above and below Lake Reality as documented by the BMAP. Dechlorination of the process water and other remedial activities at the Y-12 Plant have lowered the concentrations of some water-borne chemical stressors; thus, exposure has decreased, followed by partial ecological recovery. Nonetheless, elevated contaminant body burdens and an excess of pollution tolerant species are still present.

- Water-borne contamination (especially mercury and PCBs) must be controlled for protection of aquatic biota. Sediment or floodplain soil removal alone will probably not sufficiently reduce those contaminant concentrations in aquatic biota. Results from in-progress EFPC studies on sediment toxicity and in-stream contaminant transfer will help clarify these relationships. The implications of this and other findings will be rigorously and systematically examined in the FS-EIS.

ES.4 REMEDIATION GOAL OPTIONS

Results of the characterization of the nature and extent of EFPC contamination and of the BRA were used to develop *remediation goal options* (RGOs) for the FS. RGOs are initial chemical-specific, numeric cleanup limits developed for each affected environmental medium. These RGOs, derived from site-specific exposure assumptions, are protective of human health and the environment and comply with ARARs. RGOs were developed for children and adults using the assumptions and results of the BRA.

The process of deriving an RGO consists of establishing an acceptable target risk value for exposure to a contaminant and back-calculating the corresponding concentration in the environmental medium under evaluation. EPA requires the use of a 10^{-6} risk level as the point of departure for determining remediation goals for carcinogens and an HI score of 1 for noncarcinogens.

The list of RGOs presented in this report includes all human health COCs that were evaluated in the Tier II risk assessment. However, this is a starting point, and remediation will *not* be required for all of these substances. Although the list will be refined during the FS, the RGOs for mercury in the agricultural setting (58 mg/kg for children and 198 mg/kg for adults) will be used for the FS alternatives screening.

Based on the results of the human health BRA, the primary pathways driving the risk assessment are the food chain pathway, the soil ingestion pathway, and the groundwater ingestion pathway. These results indicated that mercury is the principal COC for EFPC. For the purposes of comparison, Fig. ES.30 shows the relative magnitude of the human health RGOs for mercury for all soil-related pathways. The RGOs are much lower for the produce pathway compared to direct soil contact. This directly reflects the conservative exposure assumptions adopted for the food chain pathways.

Groundwater is not currently a source of drinking water in Oak Ridge, nor is it likely to be used as such in the future. Risk assessment of hypothetical exposure to groundwater was conducted to comply with EPA requirements and to develop an additional measure of the significance of observed levels of chemicals. Risk assessment examined exposure to both unfiltered and filtered samples. Even if groundwater were used as a source of drinking water, it is very unlikely that the unfiltered water would be representative of the water ingested by homeowners. A more representative sample is the filtered groundwater. Although concentrations of COCs in the filtered groundwater are below federal MCLs, the risk assessment indicates that both the risk measures exceed the target levels, primarily because of the presence of arsenic and manganese. High levels of manganese are naturally found within the area. Observed levels in soils of EFPC are indistinguishable from background. Arsenic cannot be identified as originating from DOE's Y-12 Plant, and the chemical is suspected to come from an area source. For the sake of completeness, however, RGOs were calculated for chemicals in groundwater.

The ecological RGOs are based on (1) analytical data obtained during sampling of biota, (2) physical media sampling carried out during Phase Ia and Phase Ib, (3) published information about the toxicity of mercury, cadmium, PCBs, chlordane, and PAHs, and (4) relationships among these findings. Ecological RGOs were derived for physical media (water, sediments, and soil) as sources of contaminants to biota by ingestion, by direct contact, or through the food chain. For example, the soil RGO is the lowest value calculated to be protective of plants, soil invertebrates, small mammals, birds, and top predators.

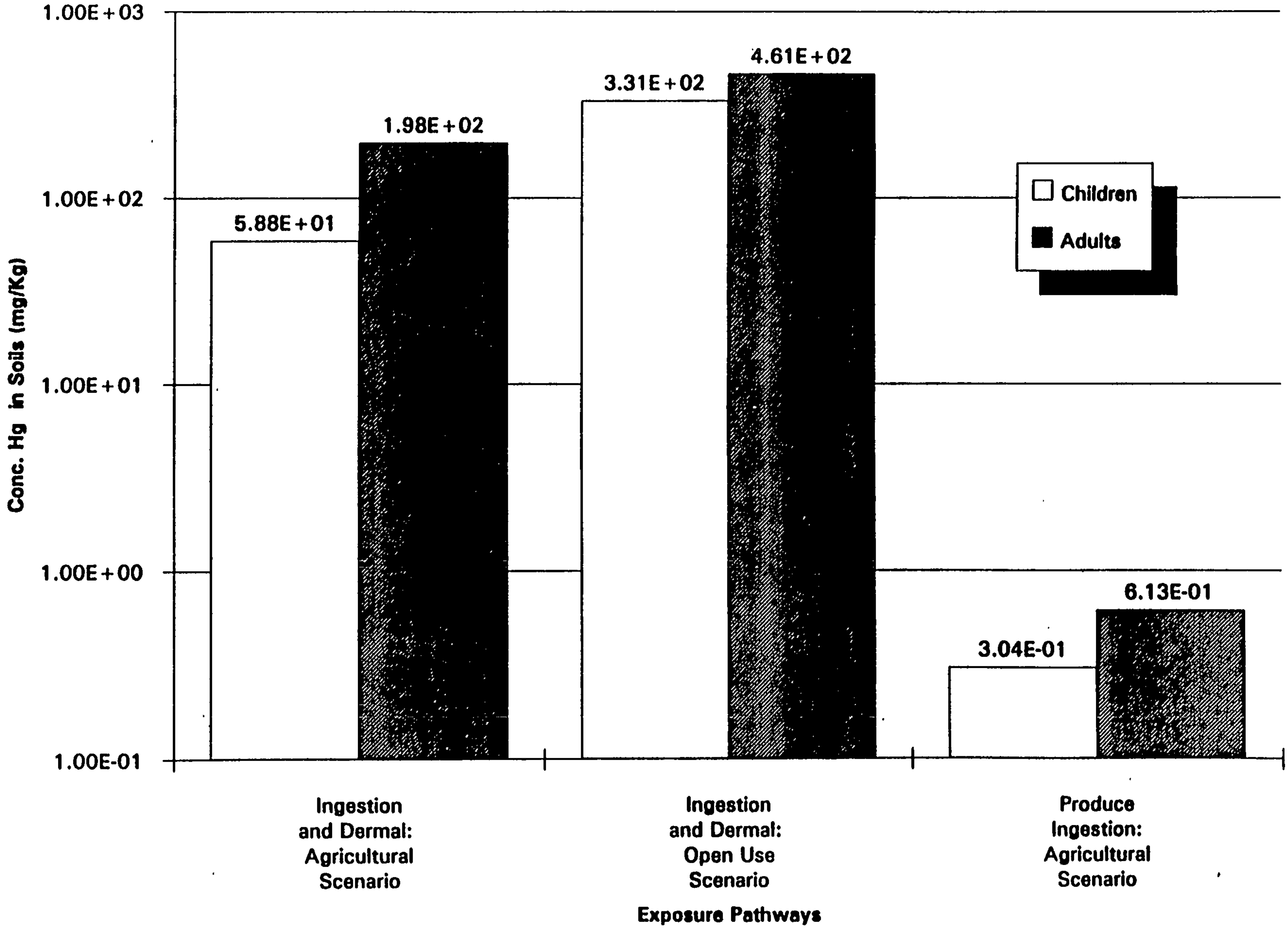

Fig. ES.30. Risk-based RGOs for mercury in soils of EFPC: protection of human health.

For mercury in sediments, an equilibrium partitioning equation was used to calculate the RGO, which was set at 210 mg/kg.

For mercury in soils, four pathways were examined. Using equations for incidental ingestion, a lower limit of 274 mg/kg was calculated. For inhalation of vapors from soil, the lower limit was 1000 mg/kg. A lower limit of 230 mg/kg has been determined from food chain equations used to calculate levels for protection from toxicity and in discussions of the food chain, especially in relation to protection from predators that would feed on contaminated prey. The RGO for mercury in soil to protect ecological resources associated with soil was set at 200 mg/kg.

To some extent, depending on flooding and erosion, sediments may be deposited and become soil, or soil may be washed into the creek and become sediment. The similarity between soil and sediment RGOs for mercury means that the distinction is not very important.

During the FS-EIS, these goals will be refined further to produce *final remediation goals.*

ES.5 RECOMMENDATIONS FOR FS-EIS DEVELOPMENT

Based on the results of the RI, BRA, and ERA, the following basic conclusions and recommendations were put forward for consideration in the development of the follow-on FS-EIS for EFPC. Although many other important findings and results are presented in earlier sections of this report, this summary is meant to reduce the large volume of information associated with this complex study into the principal guidance for remediation planning. This guidance is presented by EFPC/SLB environmental media of concern for ease of incorporation into the follow-on studies.

ES.5.1 Surface Water

There is currently no excessive risk to human health associated with contaminants in surface water in EFPC, and in general the mercury concentrations are below drinking water standards (except on occasion in the upper reaches of the stream). Nonetheless, the preponderance of risk to aquatic biota comes from water-borne contaminants currently being released from the Y-12 Plant (which does not fall within the EFPC OU). These releases appear to be (1) contributing the major initial source of the elevated mercury and other contaminant levels in aquatic biota in EFPC; (2) affecting the fish and benthic macroinvertebrate community structure, resulting in communities dominated by species tolerant of degraded water quality conditions; and (3) resulting in reduced taxonomic richness and diversity in fish and benthic macroinvertebrate communities in EFPC compared to uncontaminated reference streams. This ongoing contaminant source must be addressed to ensure protection and long-term recovery of the EFPC ecological community.

ES.5.2 Groundwater

Groundwater is not currently being used in the vicinity of EFPC as a source of drinking water, nor is it likely to be used as such in the future. This pathway was included in the BRA to comply with EPA requirements to comprehensively evaluate the groundwater pathway for current and future scenarios. Risk of hypothetical exposure to groundwater was evaluated separately for soil horizon wells and for water from the underlying bedrock (for both filtered and unfiltered samples). The BRA demonstrates that unfiltered levels of inorganic contaminants are primarily responsible for the risk levels that exceed EPA target ranges (manganese for noncancer risk and arsenic and beryllium for cancer risk). It should be noted that levels of manganese and beryllium in the soils are demonstrated to be indistinguishable from background (i.e., they are clearly naturally occurring). Exposures to waters from the soil horizon and bedrock are currently incomplete pathways. Furthermore, since the soil horizon cannot yield sufficient quantities of water for domestic or commercial uses, it is not considered a complete future exposure pathway. Remedial planning during the FS must consider whether cleanup is necessary for these inorganic chemicals for groundwater in the bedrock.

ES.5.3 Soils

Floodplain soils contain the highest levels of contaminants of all the EFPC environmental media. COPCs in the soils consist of inorganic trace metals, PCBs, PAHs, and radionuclides. COPCs were identified by dividing the average concentrations of contaminants by their chronic toxicity values for human health (or multiplying concentrations by cancer slope factors) and ranking the results; contaminants that contributed to the top 99% of the scores were retained as COPCs. Mercury was identified as the principal nonradiological contaminant through this screening process, and uranium was identified as the primary radiological contaminant. Both of these contaminants are directly attributable to the past operations of the Y-12 Plant.

Five million cubic feet of contaminated soil have been calculated to exist within the floodplain and SLB. The results of the BRA indicate that soil ingestion is an exposure pathway of principal concern to human health. The ERA also identified the soil pathway as a concern to EFPC biota, primarily through terrestrial predator food pathways. RGOs have been derived for the observed chemical contaminants in soil for use in the initial screening of remediation alternatives in the FS-EIS. The ecological RGO for mercury in soil is 200 mg/kg. Final remediation goals will be determined as part of the CERCLA process leading to a Record of Decision. Incorporation of quantified ecological goals and approved human health goals, in conjunction with the results of the soil contamination data, will identify locations where soil remediation may be required.

ES.5.4 Sediments

Creek sediments contain the same contaminants as floodplain soils, but at lower concentrations. Because of the transient nature of the sediments within the EFPC, however, the distribution of the contaminants is less predictable than in the soils. The same general patterns do exist, with the upper reaches of the creek showing somewhat elevated levels of the sediment contaminants (primarily mercury). Due to the nature of the sediments and their generally lower levels of contamination, the BRA identified little risk to human health via this environmental medium. The RGO established for mercury in sediments for children was 61,000 mg/kg, a value which essentially eliminates this medium from remediation concern for human health considerations.

The ecological impact of the contaminated sediment pathway, while only partially understood at this point, might be significant. Two studies are currently underway by DOE to assess EFPC sediment toxicity and contaminant transfer from sediments to aquatic biota. Results from these studies will help clarify the relationship between EFPC sediments and effects on aquatic organisms. However, due to the ongoing contaminant releases into upper EFPC from the Y-12 Plant, assessment of remedial alternatives for sediments should be deferred from the FS-EIS until such time as the releases from the Y-12 Plant are eliminated. Contaminant body burdens of mercury in aquatic biota, particularly in benthic invertebrates and aquatic predators, indicate a potential for significant bioaccumulation of contaminants in the food chain. The ecological RGO has been determined to be 210 mg/kg for sediments.

ES.5.5 Air Pathway

No COPCs have been measured in air along the EFPC or within the vicinity of the ORR that are of human health or ecological concern. This pathway, therefore, should be eliminated from remediation consideration in the FS-EIS.

ES.5.6 Direct Radiation

Direct radiation measurements made along the EFPC floodplain documented the background levels of direct exposure resulting from natural and man-made radionuclides. Therefore, risk assessment was not conducted for irradiation exposure. Risk assessment was conducted for radionuclides to evaluate exposure via ingestion and inhalation. No substantial human health or ecological impacts from these background levels were determined from the BRA or ERA studies (i.e., risks fell within the target ranges established by EPA).

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